DOCUMENT RESUME

ED 351 208 SE 053 438

AUTHOR Helgeson, Stanley L.
TITLE Problem Solving Research in Middle/Junior High School Science Education.
INSTITUTION ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Columbus, Ohio.
SPONS AGENCY Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE Dec 92
CONTRACT RI88062006
NOTE 95p.
AVAILABLE FROM ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Suite 310, 1200 Chambers Road, Columbus, OH 43212 ($12.50).
PUB TYPE Information Analyses - ERIC Clearinghouse Products (071)

EDRS PRICE MF01/PC04 Plus Postage.
DESCRIPTORS *Cognitive Development; Cognitive Processes; *Critical Thinking; Educational Research; Elementary Secondary Education; Heuristics; Junior High Schools; *Literature Reviews; Middle Schools; *Problem Solving; Process Education; Research Reports; Science Curriculum; *Science Education; Test Reviews; *Thinking Skills
IDENTIFIERS Science Process Skills

ABSTRACT

Problem solving has been a concern of science education for at least three quarters of a century. This book presents a comprehensive review of the research that has occurred in problem solving. The studies included in this summary range across the continuum. Some are concerned with gaps between conditions and resolutions; some involve science process skills; most in one way or another involve classroom exercises. All have in common a concern for problem solving in the science classroom. Although the primary concern in this summary is with science at the middle grades, some studies that extend into the elementary grades and into the high school years have been retained. Major sections of this book include definitions of problem solving, the assessment of problem solving, problem solving strategies and behaviors, gender differences, cognitive style and problem solving, cognitive development and reasoning ability, instruction and problem solving, and science curricula. (Contains over 130 references.) (PR)

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Problem Solving Research in Middle/Junior High School Science Education

Stanley L. Helgeson

December 1992

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Problem Solving Research in Middle/Junior High School Science Education

Stanley L. Helgeson

December 1992

Produced by the

ERIC

Clearinghouse for Science, Mathematics and Environmental Education
The Ohio State University
1200 Chambers Road, Third Floor
Columbus, OH 43212

PRINTED WITH SOY INK

Cite as:

Helgeson, Stanley L. (1992). *Problem solving research in middle/junior high school science education.* Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

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This publication was funded by the Office of Educational Research and Improvement, U. S. Department of Education under contract no. RI-88062006. Opinions expressed in this publication do not necessarily reflect the positions or policies of OERI or the Department of Education.

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Table of Contents

Introduction 1
Definitions of Problem Solving 1
Assessment of Problem Solving 5
SISS Process Test Skill Categories 10
Summary 15
Problem Solving Strategies and Behaviors 17
Summary 21
Gender Differences Related to Problem Solving 23
Summary 26
Cognitive Style and Problem Solving 27
Summary 29
Cognitive Development and Reasoning Ability 31
Summary 41
Problem Solving and Instruction 43
Summary 57
Science Curricula and Problem Solving 59
Summary 67
References 69

A Brief Guide to ERIC 83
Adjunct Clearinghouses 89
Support Components 90
How to Submit Documents to ERIC 91

Introduction

Problem solving has been a concern of science education for at least three quarters of a century. In examining 60 years of literature as represented by articles published in *Science Education*, **Champagne and Klopfer** (1977) note that the first article in the first volume of the journal (then named *General Science Quarterly*), written by John Dewey, asserted that "the method of science—problem solving through reflective thinking—should be both the method and valued outcome of science instruction in America's schools" (p. 438). The origin of this concern may be attributed to an earlier work of **Dewey** (1910) in which he listed "five logically distinct steps" in the "act of thought":

(i) a felt difficulty;

(ii) its location and definition;

(iii) suggestion of a possible solution;

(iv) development by reasoning of the bearings of suggestion;

(v) further observation and experiment leading to its acceptance or rejection, that is, the conclusion of belief or disbelief. (p. 72)

A clear link between science and problem solving is noted by **Simon** (1981): "...scientific discovery is a form of problem solving, and...the processes whereby science is carried on can be explained in terms that have been used to explain the processes of problem solving..." (p. 48).

Definitions of Problem Solving

While there is substantial agreement among science educators on the importance of problem solving in school science, there is much confusion and inconsistency in the terminology used related to problem solving. Instead of defining problem solving, science educators have often tried to categorize and describe the process by which solutions are obtained. In addition to problem solving, terms used include scientific method, scientific thinking, critical thinking, inquiry skills, and science processes (**Champagne and Klopfer**, 1981).

Careful attention was paid to process skills in the development of *Science - A Process Approach* (SAPA), which represented "an attempt to establish the specific competencies in students which will make it possible for them to solve problems, to make discoveries, and more generally think critically about science...." (**Gagne**, 1965:7). The basis for this approach was further elucidated by **Gagne** (1970) in discussing varieties of learning, each of which establishes a kind of capability in the learner. This capability may be narrowly specific, as in responding to a signal, or it may range in generalizability to the kind of competence attained in rule learning or problem solving. "But in all cases, the

capability itself embodies an identifiable *intellectual skill*, something that the learner is able to do with reference to his environment." (p. 237). He notes that the processes underlying SAPA are equivalent to these intellectual skills and can be categorized under the general names of observing, classifying, measuring, using space/time relations, using numbers, communicating, and inferring. Integrated processes include formulating hypotheses, defining operationally, manipulating variables, interpreting data, drawing conclusions, and, as the most complex activity of all, experimenting (pp. 260-266). Gagne later says:

> Problem solving may be viewed as a process by which the learner discovers a combination of previously learned rules which can be applied to achieve a solution for a novel problem situation.
>
> Problem solving is not simply a matter of application of previously learned rules, however. It is also a process that yields new learning. (1977:155)

In what is essentially an operational definition, **Shaw** (1983) defines problem solving skills to include the four integrated processes of interpreting data, controlling variables, defining operationally, and formulating hypotheses.

Hayes (1981) takes an approach that is, perhaps, both simpler and more comprehensive:

> Whenever there is a gap between where you are and where you want to be, and you don't know how to find a way to cross that gap, you have a problem. Solving a problem means finding an appropriate way to cross a gap (p. i).

Much of the difficulty in determining what constitutes problem solving **Smith** (1991) attributes to the existence of a dichotomy in the definition of "problem." On the one hand are the "gap" definitions that imply a solver's lack of knowledge of an appropriate solution method. On the other are the "exercises," for which the solver has available some strategies to apply in attempting a solution. Smith argues that exercises should be included in the definition. He makes the case that research is designed to understand problem solving in the classroom and thereby to affect classroom instruction on problem solving. While much of classroom problem solving includes tasks that might be considered exercises, they are often tasks for which the student may know appropriate procedures but is not yet adept in applying these procedures or in matching these procedures to appropriate problems (p. 6). What Smith proposes, then, "is a 'continuum definition,' a definition that ... embraces all tasks that fall along the continua from exercise to 'real problem,' from simple to complex, from familiar to unfamiliar" (p. 7). But problem solving requires more than simple recognition or recall from memory. Smith summarizes accordingly:

> A problem is any task that requires analysis and reasoning toward a goal (or "solution"). This analysis and reasoning must be based on an understanding of the domain from which the task is drawn. A problem cannot be solved by recall, recognition, or reproduction....
>
> Whether or not a task is defined as a problem is not determined by how difficult or by how perplexing it is for the intended solver. "Problem solving," therefore, becomes the process by which a system generates an acceptable solution to such a problem (p. 8).

The studies included in this summary range across the continuum. Some are concerned with gaps between conditions and resolutions; some involve science process skills; most in one way or another involve classroom exercises. All have in common a concern for problem solving in the science classroom. Although the primary concern in this summary is with science at the middle grades, some studies that extend into the elementary grades and into the high school years have been retained.

Assessment of Problem Solving

Assessment of problem solving reflects some of the ambiguity noted in the various definitions of problem solving. The close relationship between problem solving and science process skills is apparent, however, even in the most cursory examination of the science education literature. In most cases problem solving is, in effect, defined by what is measured or assessed, and often this includes at least some aspect of the processes of science. In an overview of measurement instruments in science, **Mayer and Richmond** (1982) note the increased attention paid to science process skills and problem solving behavior in the curriculum development activities of the 1960s. Much of the effort in assessing problem solving appears to derive from these curriculum development activities. The assessment instruments reviewed here fall generally into four categories: (1) those including defined behaviors or strategies of problem solving, (2) those dealing with science process skills in general, (3) those restricted to the integrated science process skills, and (4) assessment of logical thinking.

Four instruments were identified that were specifically designed to evaluate problem solving. In each of these cases problem solving was defined by specified strategies or behaviors. One of the earliest of these instruments was reported by **Butts** (1964), **Jones** (1966), and **Butts and Jones** (1966). Originally called the *X-35 Test of Problem Solving*, the name evolved to the *Tab Inventory of Science Processes* (TISP) and later became better known as the *Tab Science Test*.

In this instrument, the child is presented with a discrepant event via a filmloop and asked to select an explanation from a given list. The student is then provided data by clue questions whose answers are covered by tabs. The student removes the tab from each desired question and places it on an answer sheet. By keeping the tabs in the order in which they were removed, the investigator can determine what questions were asked and in what order they were asked. When a possible correct explanation has been found, the student can check it against the same list of explanations given in the first section of the test. Under each tab is a yes or no indicating whether the explanation is correct. The student continues processing data until a correct explanation is found. The construct validity of the *Tab Science Test* was examined by analyzing the pre-and post-test scores of students who were involved in an inquiry training program. A significant correlation ($p<.05$) was found for the inquiry pupils but not for the control students, supporting the construct validity of the test. Reliability was determined by calculating the coefficient of equivalence for two forms of the instrument, which indicated that the two forms were statistically equivalent ($p<.05$).

The *TAB Science Puzzler*, derived from the *Tab Science Test*, was designed by **Norton** (1971) as a measure of problem solving performance. The five subtasks of the test coincide with steps of a problem solving model: (1) Problem Orientation, (2) Problem Identification, (3) Problem Solution, (4) Data Analysis, and (5) Problem Verification. The test was administered to 27 fourth, fifth, and sixth grade children to determine if there was a relationship between problem

solving performance and: (1) previous science knowledge; (2) selected cognitive factors of intelligence; and (3) IQ, age, or reading ability. Inter-form reliabilities of the instrument ranged from 0.42 to 0.80. He found that: (1) problem solving performance was related to previous science knowledge; (2) the selected cognitive factors were not related to total problem solving performance, but flexibility and speed of closure and reasoning were related to the subtasks of Problem Orientation, Possible Solution, and Data Analysis; and (3) there was no evidence to support a relationship between problem solving performance and IQ or reading ability, but age appeared to be related to problem solving in certain problem areas.

As a part of the evaluation of the *Unified Science and Mathematics for Elementary School* (USMES) program, **Shann** (1976) developed the *Test of Problem Solving Skills* (TOPSS), a group-administered, paper and pencil, multiple-choice instrument. Criteria for test items were that the items: (1) measured understanding of the processes of science, (2) drew from real-life experience, and (3) were written for elementary school children. Thirty items were selected from the science subtest of the *Sequential Test of Educational Progress* (STEP), which was designed to measure the following skills: (1) define problems, (2) suggest hypotheses, (3) select procedures, (4) draw conclusions, (5) evaluate critically, and (6) reason quantitatively. In addition, 22 items were developed to complete the new problem solving test.

A total of 398 students in grades four, five, and six were administered the test. Based on the results of this testing, Shann recommends omitting six of the items, yielding a final instrument of 46 items. Reliability (Hoyt) for the total test of 46 items was found to be 0.86. Because problem solving was considered to be a construct, the test was validated by construct validation. This involved looking for other behaviors that would correlate with scores on the instrument such as (1) growth in problem solving skills from grade four to six indicated by sixth graders achieving higher scores than would fourth graders (supported); (2) high positive correlation between teachers' ranking of students' abilities in problem solving and student scores on the test (supported); (3) Part I of the test (items from STEP test) correlating well with the constructed items of Part II (supported); and (4) USMES students who had experience with a unit that served as a basis for items in Part II would score higher than USMES students without such experience but who, in turn, would score higher than non-USMES students (not adequately tested). Shann concluded that there was "evidence for the effectiveness of this new test as a reliable, valid and practical measure of the problem solving skills of elementary school students" (p. 96).

Ross and Maynes (1983a) developed a multiple-choice test for seven problem solving skills in science using learning hierarchies based on expert-novice differences. The seven skills were: (1) developing a focus (hypothesis formulation), (2) developing a framework (designing an experiment), (3) judging the adequacy of data collected, (4) recording information, (5) observing relationships in data, (6) drawing conclusions, and (7) generalizing. Learning hierarchies were constructed for each skill by contrasting the cognitive behavior

of novices with the cognitive behavior of sophisticated problem solvers. A pool of multiple choice items was developed for each skill using a sample of science experiments encountered by seventh and eighth grade students. The items were field tested in three phases: first in a pilot test, then a field test with 1010 students, and, finally, a second field test of two forms of the test with 590 students. Internal reliabilities (Hoyt) for the two forms of the test ranged from 0.58 to 0.69; test-retest reliability (Cronbach's alpha) was 0.722 for form A and 0.789 for form B; equivalent form reliability (Cronbach's alpha) was 0.759 when the tests were given in A-B order and 0.705 when the tests were given in B-A order. The internal consistency of the tests is fairly weak because the skills being measured are discrete components of the same domain—problem solving.

The face validity of the instruments was established in the development stage by including items for testing only when there was unanimous agreement that two criteria had been met: (1) the stimulus portion had to describe an experiment that could be encountered by seventh and eighth grade students, and (2) each response option had to match one level of the learning hierarchy for the designated skills. The best evidence for construct validity was provided by students who were given instruction in three of the skills. Their total pretest scores tended to correlate positively with total posttest scores (0.402 and 0.576 for the two groups, respectively), establishing modest predictive validity. The tests were also found to be sensitive to instruction. A statistically significant advantage for the treatment group was found on the skills taught, and no significant differences between control and treatment groups on untaught skills. Ross and Maynes concluded that the tests can be used to measure experimental problem solving skills, albeit with some caution, to make some judgments about group performance.

Another group of four instruments assessed students' science process skills, including the basic skills, while a fifth instrument incorporated enquiry skills. The sixth instrument in this group required hands-on manipulation of equipment and materials. The *Test of Science Processes* (TOSP), was constructed by **Tannenbaum** (1969) to assess the ability of junior high school students to use the science processes of observing, comparing, classifying, quantifying, measuring, inferring, experimenting, and predicting. The instrument, consisting of 96 multiple-choice items, was administered to 3673 students selected to include all ability levels and a wide range of socioeconomic backgrounds. A total score reliability (KR–20) of 0.91 was calculated; subscale reliabilities for each of the eight processes ranged from about 0.30 to about 0.80. Criterion-related validity was determined through correlation of student scores with teacher ratings of the students' abilities to use science processes. The correlations ranged from 0.12 to 0.48, indicating some degree of criterion-related validity.

The *Science Process Skills Test* (SPST), developed by **Moliter and George** (1976), was designed to evaluate the performance of children (n=356) in grades four, five, and six on the inquiry skills of inference and verification. The items were designed to be as content-free as possible, and items and distractors were presented as illustrations to avoid reading problems. The final form of the

instrument consisted of nine inference and nine verification items. The reliability (KR–20), determined for the three grades ranged from 0.539 to 0.589 for the inference subtest and from 0.714 to 0.838 for the verification subtest. Item discrimination, determined in the form of a corrected biserial correlation between each item and the appropriate subtest, was 1.00 for the verification subscale for all three grades and ranged from 0.44 to 0.77 for the inference subscale. The results of the investigation indicated that not all items on each subtest were capable of eliciting the skill behavior defined by the stipulated performance criteria. The evidence suggested that the verification and inference subtests had some degree of construct validity.

The development of a science processes test using external criterion-referenced validation and an objective method of item selection was reported by **Ludeman** (1975). A pool of items intended to assess students' ability to use the processes of science was generated, and a subset of the *Individual Competency Measures* from the *Science-A Process Approach* (SAPA) program was used as the external criterion. These Competency items and the previously generated items were administered to a group of students. Items from the pool were then selected based on their ability to discriminate between students who did well and students who did poorly on The Individual Competency Measures. Norming data for the final form of *The Science Processes Test* (TSPT) were obtained by administering it to 1301 sixth grade students randomly selected from 19 public schools. In its final form, the TSPT consists of 36 four-alternative multiple-choice questions. The correlation of the validating sample scores on TSPT and their scores on the Individual Competency Measure was 0.83. The reliability (KR–20) was 0.842, mean difficulty was 0.503, and the mean discrimination was 0.496. The author concluded that TSPT was a useful test for assessing students' ability to use the processes of science.

A multiple-choice test of *Basic Process Skills in Science* (BAPS) appropriate for students in grades three through eight was developed by **Cronin, Twiest and Padilla** (1985). The objective was to develop a reliable multiple-choice test of six basic science process skills: observation, inference, prediction, measurement, communication, and classification. Criteria for development included: (1) an emphasis on the six most widely used basic science process skills; (2) a multiple-choice, four-option format; (3) an emphasis on pictures and drawings to clarify and enhance items; (4) average test readability below the fourth grade level; (5) test length permitting completion within one class period (45 minutes or less); (6) wide range of difficulty of items addressing each process skill; and (7) content-free test items. The 36-item test was subjected to readability analysis and found to have an average index of 3.95. A panel of four science educators examined the instrument and reported strong evidence of content validity.

The test was administered to 133 fourth, sixth, and eighth grade students. Scores ranged from 4 to 33 correct with a mean of 22.4 and standard deviation of 5.3. The overall reliability (KR–20) was 0.78; average item difficulty was 0.62; average item discrimination (point biserial correlation) was 0.34.

Twiest and Twiest (1989) modified the BAPS to include new graphics and corrected some items, and validated the instrument with parallel station tests (using actual demonstrations) and interviews. The final version of the BAPS test was administered to 390 students in grades four through eight. The overall reliability (KR–20) was 0.72; scores ranged from 13 to 36 with a mean of 29.22 and standard deviation of 3.94; average item difficulty was 0.80; and the average item discrimination index was 0.29. The station test (BAPSST) was administered to 113 students in grades four through eight. The overall reliability coefficient (KR–20) was .80; scores ranged from 6 to 32 correct with a mean of 22.29 and a standard deviation of 5.43; 15 items had discrimination indices above 0.40 while eight items had indices below 0.20. The interview test (BAPSIT) was administered to 41 students in grades four through eight. The overall reliability coefficient (KR–20) was 0.80; scores ranged from 9 to 30 with a mean of 21.73 and a standard deviation of 5.42; average item difficulty was 0.58; discrimination indices ranged from 0.12 to 0.62 with an average value of 0.34. Correlations of the BAPS with the station and interview tests, corrected for attenuation, were 0.78 and 0.80, respectively, implying that the tests were measuring the same constructs. All three tests appear to be valid and reliable methods for measuring basic science process skills.

The Test of Enquiry Skills (TOES) developed by **Fraser** (1979) measures nine separate enquiry skills that fall into three major groups. The first group of scales measures skills related to using reference materials such as dictionaries, encyclopedias and library catalogs, or a book's table of contents or index. The second group of scales measures skills related to reading and processing information such as reading various scales; calculating averages, percentages and proportions; interpreting charts and tables; and using graphical materials. The third group of scales measures three critical thinking-in-science-skills, namely, comprehension of science reading material, design of experimental procedures in science, and the ability to draw generalizations and conclusions from data (p. 1).

The enquiry skills considered most important by experts were identified by a literature search and a pool of items developed to form the basis of the instrument. The items were examined and then rewritten in light of reactions by teachers and experts in educational measurement about each item's clarity, readability, face validity, and scale allocation. After field testing, a final version of the instrument was administered to a sample of students in Years 7 through 10.

The resulting scores showed that mean performance at a given grade level varied markedly from skill to skill; however, the average performance on all TOES scales increased with grade level. Standard deviation tended to decrease as Year (grade) level increased. The mean internal consistency reliability (KR–20) values ranged from 0.72 for Year 7 scores to a low of 0.59 for Year 10 scores; the decrease in the sizes of KR–20 values would be anticipated in view of the observed decrease in standard deviation. Test-retest reliabilities were obtained for samples of Year 7 students and found to range from 0.65 to 0.82, with a mean of 0.73 for the nine scales. Thus, the reliability of the instrument was deemed to be satisfactory (p. 5).

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The final test in this group is the only assessment device reviewed that required the actual manipulation of laboratory equipment and materials in a practical setting. As part of the Second IEA Science Study (SISS), six countries, including the U. S., administered science laboratory skills tests to students in Grades 5 and 9 (**Jacobson and Doran, 1988; Kanis, Doran, and Jacobson, 1990**). For the SISS process skills tests, a three-category system of skills was selected:

SISS Process Test Skill Categories	
Skill	**Illustrative Components**
Performing	observing, measuring, manipulating
Investigating	planning and design of experiments
Reasoning	interpreting data, formulating generalizations, building and revising models

(Kanis, Doran, and Jacobson, 1990:14)

The process skill tasks were also classified by content, examined for content validity by comparison with curricular grids provided by the International Study Committee, and analyzed by members of the SISS National Committees and by science educators in the different participating countries.

The test is composed of six tasks at Grade 5 and six tasks at Grade 9. The tasks were divided into two sets of three at each grade level for administration purposes. Each student participating in the study attempted three tasks belonging to one set. Each task contains one or more problems that the students are to solve. The tasks are built up of several elements or items. Some items help the students to structure the problem, others to check their results. Examples of the tasks include for the fifth grade, "Describe and explain color change of bromothymol blue solution after blowing through a straw," and, for the ninth grade, "By testing with battery-bulb apparatus, determine the circuit within a 'black box'" (Jacobson and Doran, 1988:68-69)

The administration of the tests utilized stations for each task with all materials and equipment required for the task located at that station. A total of 45 minutes per set was required for testing. Students had ten minutes to work at each task, two minutes for clean up, and one minute between tasks to move to the next station.

The U. S. data were collected in 1986 with a sample of 2,585 fifth grade students and 2,248 ninth grade students. It was found that, in general, students at both grade levels "were quite successful at tasks requiring manipulative skills

(performing, measuring, etc.) but less successful at investigating and reasoning skills" (Jacobson and Doran, 1988:79). Although girls performed better than boys on some life science tasks and boys performed better than girls on some physical science tasks, the overall achievement of boys and girls on these skills tests was very similar.

In addition to measuring skills not easily assessed by traditional paper and pencil methods, practical exercises provide a means of gaining insights into student patterns of thinking and methods of problem solving. Thus, the practical test is an instrument that can be effectively used to identify misconceptions and misunderstandings (Jacobson and Doran, 1988:75).

The integrated science process skills served as the focus of seven instrument development efforts. **Fyffe** (1972) and **Robison** (1974) collaborated on developing *A Group Test of Four Processes* to measure process skill development for the four integrated process skills: controlling variables, interpreting data, formulating hypotheses, and defining operationally. The 79-item, multiple-choice instrument was administered to 56 seventh grade students who had taken *Science-A Process Approach* (SAPA) in sixth grade. Face validity was established by a panel of experts. Item analysis showed that an index of item discrimination of 0.20 or greater existed for 13 items for the process of controlling variables, for 22 items for the process of interpreting data, for 10 items for the process of formulating hypotheses, and for 11 items for the process of defining operationally. Items with an index of discrimination less than 0.20 were deleted from the instrument. Concurrent validity was established by correlating student scores on the *Individual Competency Measures* from SAPA (the external criterion) and scores on the Group Test. It was found that there was a significant correlation (at the 0.001 level) between the individual and group scores for each of the four integrated processes, supporting the criterion validity of the Group Test (**McLeod, Berkheimer, Fyffe, and Robison**, 1975).

As part of a study to examine the effect of a process-oriented curriculum (SAPA II) upon problem solving skills, **Shaw** (1982) developed a process skills test, using a paper and pencil, multiple-choice, group testing format. Problem solving skills were defined as including the integrated process skills of interpreting data, controlling variables, defining operationally, and formulating hypotheses. Objectives were developed for each of the science processes, and items appropriate for the objectives were constructed. Because the purpose of the test was to evaluate the transfer of problem solving skills to new content, the items were designed to exclude science content covered during the treatment. Content validity was established by three science educators who evaluated each item on the basis of whether each item: (1) tested the stated objective, and (2) was technically sound. Items were included only when all three experts agreed that they met both criteria.

The test was administered to 147 sixth grade students. The 60-item *Objective Referenced Evaluation in Science* (ORES) was determined to have a reliability (KR–20) of 0.924. Although the test was developed for sixth grade students, the author indicates that it would also be appropriate for seventh and eighth graders.

The next four instruments in this group effectively constitute a series with the first test as the basis from which the others derive. The *Test of Integrated Process Skills* (TIPS), designed by **Dillashaw and Okey** (1980), is a 36-item multiple choice test for middle and secondary school students covering content from all science areas. The items have four possible responses and are related to five integrated process skills: hypothesizing, identifying variables, operationally defining, designing investigations, and graphing and interpreting data. The test was administered to 709 students in grades 7 through 12. Based upon the data from these students, the mean of the test was determined to be 18.99 and the standard deviation, 7.60. Reliability of the test (Cronbach's alpha) was 0.89; the mean item discrimination index was 0.40 and the average item difficulty index was 53%. An estimate of the readability index was 9.2.

Because of the continued need for and relative scarcity of process skills tests for middle and high school grades, **Burns, Okey, and Wise** (1985) developed another set of test items aimed at the same set of science process skills assessed by the TIPS instrument. The new instrument, called TIPS II, is also composed of 36 multiple choice items and can be administered in a typical class period. Following piloting and revision, the TIPS II was administered to students (n=459) in grades 7-12. Results for all students yielded a mean score of 19.14, a standard deviation of 6.93, and a total test reliability (Cronbach's alpha) of 0.86. Mean difficulty and discrimination indices were 0.53 and 0.35, respectively. Split-test correlations between TIPS II and the original TIPS items were 0.80 and 0.90. The authors concluded that the TIPS II is a reliable instrument for measuring science process skill achievement and that it increases the available item pool for measuring these skills.

A project to develop a middle grades integrated process skills test (MIPT) was reported by **Cronin and Padilla** (1986). The criteria for the test were: (1) an emphasis on the skills associated with experimenting; (2) multiple-choice, four-option format; (3) average test readability below the seventh grade level; (4) test length to permit completion within one class period (45 minutes); (5) a wide range of difficulty of items addressing each identified skill; and (6) content-free test items. A 40-item test with an average grade level readability of 6.1 was developed and administered to 1154 seventh grade students. Scores on the MIPT ranged from 6 to 40 correct (mean=27.14, s.d.=7.69) with a standard error of measurement of 2.73. The overall reliability (KR–20) of the MIPT was 0.89. Item difficulties ranged from 0.24 to 0.89, with an average of 0.68. Point biserial correlations (discrimination indices) were above 0.30 for 39 of the 40 items, with an average value of 0.43.

The results were interpreted by the investigators as indicating that most items were functioning quite well, making the MIPT useful for evaluating the integrated process skill performance of middle school students.

The *Performance of Process Skills* (POPS) *Test*, based on refined and modified items of the MIPT, was developed by **Mattheis and Nakayama** (1988) in an attempt to construct a valid and reliable non-curriculum-specific measure

of integrated science process skills intended for use with middle school students. Six process skill objectives were identified to form a basis for the POPS test items: identifying experimental questions, identifying variables, formulating hypotheses, designing investigations, graphing data, and interpreting data. From the pool of 40 MIPT items, the 21 items judged to be the best measures of the identified process skills were selected for inclusion in the POPS test. After modification of the items, the POPS test was administered to 1402 students in grades six through eight. Scores ranged from 1 to 20 with a mean of 9.77 and standard deviation of 4.16. Total test reliability (KR–20) was .75; mean item difficulty was .47. The mean item discrimination, obtained by using the upper 27% and lower 27% of the group, was 0.49. An average grade level readability index of 6.8 for the test was obtained using the FOG index.

The authors consider the POPS test to be a reliable and valid instrument for diagnostic or summative assessment in science classes or research studies, useful in evaluation of instruction and learning, curriculum validation, and assessing process skills competence of middle school students.

Although not part of the same line of development as the preceding four instruments, the last test in this group is closely related in orientation. Based on the belief that students should be involved in predicting relationships between variables and attempting to quantify these relationships, **McKenzie and Padilla** (1986) developed the *Test of Graphing Skills* (TOGS). Nine objectives encompassing the skills associated with constructing and interpreting line graphs were written and refined. The content of the objectives included selecting appropriate axes, locating points on a graph, drawing lines of best fit, interpolating, extrapolating, describing relationships between variables, and interrelating data displayed on two graphs. Twenty-six multiple-choice items were constructed to measure the objectives and submitted to a panel to establish content validity, resulting in 94% agreement on assignment of item to objective and 98% on scoring of the item. The revised version of the test was administered to 377 students in grades seven, nine, and eleven. Total scores ranged from 2 to 26 correct with a mean score of 13.3 and standard deviation of 5.3. The reliability (KR–20) was 0.83 and the average discrimination index (point biserial correlation) was 0.43.

It was concluded that the TOGS was a valid and reliable instrument for measuring graphing abilities. The authors note that with the increased emphasis on multiple sources of data for decision making and the availability of large amounts of data, ways of condensing and interpreting data are becoming more important. Because experimenting and other data-collecting activities pose an opportunity to practice such skills in the science classroom, it seems natural that teaching line graph construction and interpretation skills should occur within the study of science.

The final group of instruments to be reviewed reflects the relationship of logical thinking, science process skills, and problem solving. The need to adapt curricula to the developmental levels of learners motivated a search by **Lawson**

(1978) for a reliable and valid *Classroom Test of Formal Reasoning*. Because formal operations include those processes that guide the search for and evaluation of evidence to support or reject hypothetical causal propositions, the items selected for inclusion in the test required the isolation and control of variables, combinatorial reasoning, probabilistic reasoning, and proportional reasoning. No items directly measuring correlational reasoning were readily available at the time the test was constructed. In addition, one item involving conservation of weight and one involving displaced volume were included. The 15 items constructed each involved a demonstration using some physical materials and/or apparatus.

The test was administered to 513 students in eighth, ninth, and tenth grades. Questions requiring a prediction were posed followed by possible answers. Students selected the best answer and wrote explanations for their choices. Scores for the entire samples ranged from 0 to 15. The distribution of scores approximated a normal curve with a mean of 7.41 and standard deviation of 4.7. The standard error of measurement was 2.0, the reliability (KR–20) was 0.78. Face validity was established by a panel of six experts who responded with 100% agreement that the test appeared to require concrete or formal reasoning.

The correlation between classroom test scores and the summed scores from the bending rods and balance beam tasks was 0.76 ($p<0.001$), documenting convergent validity. Factorial validity was established by principal components analysis indicating three factors: formal reasoning, concrete reasoning, and "early formal" reasoning. Lawson concluded that the same psychological parameters measured by classical Piagetian interviews were measured by the classroom test with a fairly high degree of reliability.

Tobin and Capie (1980, 1981) selected items from the test developed by Lawson to construct the Test of Logical Thinking (TOLT), a ten-item test for students of middle school age and older. The instrument contains two items related to each of five modes of logical thought: identifying and controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning. The test uses a double multiple-choice format in which a student is presented with a problem and asked to select a correct answer from among five responses, and then to select a reason for the answer from among five choices. To be correct, the student must choose both the right answer and the correct reason. This minimizes the effect of guessing and results in high test reliability with relatively few test items. The TOLT was validated with both college and secondary school students by correlating its items with performance on tasks presented using traditional Piagetian interviews. A correlation of 0.76 was obtained between TOLT scores and interview tasks in which formal reasoning was used. Predictive validity was determined to be 0.74 and construct validity, determined by factor analysis, indicated the presence of a strong factor that accounted for 33% of the variance. Reliability for the TOLT (Cronbach's alpha) was found to be 0.84. The evidence thus supports the TOLT as being a valid, reliable measure of formal reasoning ability.

Because the existing tests of cognitive development measured no more than five modes of reasoning and most were influenced by students' reading and writing ability, **Roadrangka, Yeany and Padilla** (1983) developed the *Group Assessment of Logical Thinking* (GALT) to measure six logical operations (conservation, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial logic). It could be reliably administered in one class period. During development, items were constructed that presented a problem (with pictorial representations of real objects) to the student who then selected the best answer and wrote a justification for that answer. These written justifications were then used to construct multiple–choice justifications. The FOG Index was used to adjust sentences to produce a written test at or above the sixth grade level. In final form the 21-item GALT was administered to 450 subjects in grades six through college. The coefficient alpha for GALT was 0.89; the internal consistency of each subtest ranged from 0.13 to 0.85. Item difficulties averaged 0.55 and item discrimination indices averaged 0.49. The mean intercorrelation coefficients for subtests averaged 0.49. A factor analysis produced a one-factor solution.

The results indicate that the GALT is a reliable instrument that adequately measures six logical operations. These results are further supported by Bitner-Corvin (1988b) in a series of five studies to determine how reliably the GALT measured logical thinking abilities. The reliability coefficients for the five samples ranged between 0.76 and 0.86, supporting the use of the GALT as a reasonable measure of logical thinking.

Summary

Assessment of problem solving at the middle/junior high school level has evolved from evaluation of defined problem solving behaviors to measurement of science process skills to evaluation of the integrated science process skills. All but one of the instruments are paper and pencil, multiple-option tests and were either developed in conjunction with evaluation of a specific curriculum or clearly derived from curricular emphases. Most recent efforts (TIPS, TIPS II, MIPT, POPS) have been concerned with the integrated science process skills identified in SAPA. The *Classroom Test of Formal Reasoning*, TOLT, and GALT represent approaches to assessment based on our increased knowledge of the learning process and the relationships among logical thinking, science process skills, and problem solving.

None of the instruments can be considered the complete solution to the difficulty of assessing problem solving. All, however, have some claim to legitimacy in measuring some aspects of problem solving. The most recent instruments, in particular, are reliable and report reasonable validity claims. In brief, instruments capable of assessing elements of problem solving are available, justifying further attempts to measure and to understand the process of problem solving.

Problem Solving Strategies and Behaviors

Several studies dealt with the kinds of strategies or behaviors exhibited by students as they engaged in problem solving. The first six studies reviewed deal with such strategies in relatively structured or guided situations. The final study in this section, however, examines a general problem solving strategy.

Schmiess (1971) attempted to determine whether sixth grade students (n=34) could successfully engage in scientific investigation. Success was measured by the students' proficiency in solving problems, interest in science, and growth in solving new problems. The investigator designed and taught a one-semester phytochemical project. Ability of the sixth graders to solve scientific problems was measured by comparing the students' investigative data with homologous professional scientific data. Pre-test and posttest scores of the SRA *"What I Like To Do" Interest Inventory* were used to determine any changes in interest in science, and the pre-test and posttest scores of the Sequential Tests of Educational Progress were used to determine changes in ability to solve new problems.

Schmiess found that: (1) The question whether sixth graders had the ability for scientific investigation could not be answered statistically; however, student data indicated that 50% of the class was accurate on 78% of their investigations. (2) The posttest scores on science interest and on solving new problems were significantly higher than pre-test scores. (3) High and average achievers were significantly higher than were the low achievers on ability to solve new problems. (4) No significant differences were obtained among high, average, and low achievers on interest; nor were there significant differences between boys and girls on solving selected science problems, interest in science, or in ability to solve new problems.

Mandell (1980) conducted a study to identify common problem solving behaviors and strategies used by sixth graders 25) who had been classified by their teachers as superior problem solvers. A secondary purpose was to determine whether the students so classified were, in fact, superior problem solvers. A series of six problems were presented in the same order to each student in individual, audiotaped interview sessions during which the students were encouraged to think aloud. The audiotapes were transcribed and analyzed.

Students were divided into successful problem solvers and nonsuccessful problem solvers for each problem. Forty-eight percent of the sample (labeled the successful problem solver group) solved one-half or more of the six problems; the other subjects comprised the nonsuccessful problem solvers group. The successful problem solvers' group means on IQ, SRA Math, and SRA Science subtests were significantly higher than the nonsuccessful problem solvers' group means on these same measures. All ten of the students who were selected by two or three teachers as superior problem solvers were in the successful problem solver group; none of them were in the nonsuccessful group. Mandell found that the students in the successful problem solvers group had certain characteristics in common:

(1) they were quick to identify the nature of the problem; (2) they were able to use all four abilities in Piaget's INRC group (identify, negation, reciprocity, and correlativity); (3) they were not dependent on physical manipulations or calculations in solving most problems; (4) they used rough tables or matrices if calculations were needed; and (5) they expressed their reasoning and procedures with ease.

Wilson (1973) investigated the effect of generating hunches upon subsequent search activities in problem solving situations by 45 students, 9-11 years of age. The students, divided into three groups, were assigned to observe a contradictory stimulus. The first group was asked to write hunches, the second group was allowed to read hunches, the third group had no hunch activities. Wilson found evidence of direct influences of generating hunches on search behaviors and quality of solutions. The findings suggest that structuring stimulus events and arranging learning conditions so that hunches are generated can influence search activities and the quality of the solutions generated. In effect, the students become more efficient as problem solvers.

Berger (1982) and **Berger and Pintrich** (1986) reported studies to examine students' attainment of skill in using science processes. A computer simulation presented a vertical line or "wall" on the right side of the screen with a circle representing a balloon touching the wall at a predetermined vertical distance. Students were to estimate the height of the balloon. As they entered their estimations into the computer, an arrow appeared on the left side of the screen, traveled to the right, and stuck in the wall at the height of the estimate. If the estimate was correct, the balloon "popped." Three basic strategies were identified: random, ladder (moving up or down systematically), and bracket.

The researchers found, among other things, that the microcomputer provided a useful and powerful tool to gather strategy data, that students used effective strategies and improved their estimation skill quickly, and that age and amount of information presented in the task affected performance. Younger students did not perform as well as older students, a finding consistent with other studies of developmental differences in learning and memory. As the amount of information available increased, students showed a decrease in reaction time, indicating that there was less demand on short term memory. With less demand on short-term memory, performance improved.

Horak (1990) investigated students' use of scientific reasoning and mathematics problem solving heuristics within computer simulations. Middle and junior high school students were observed as they worked with computer programs requiring problem solving skills. Audiotapes and records of computer keystrokes were recorded for each student and analyzed to identify any differences and similarities in approaches in students' selected problem-solving strategies.

Three public-domain computer programs were used in this study. "House Builder" is a non-competitive problem solving situation requiring students to collect and analyze data in order to solve future problems. "Select the Environment" requires students to devise solutions to an environmental problem where species

of plants and animals are in danger of extinction; it is non-competitive, but requires players to solve the problem within a prescribed period of time. "Make it 21" is an adversary game in which the computer is an expert player and the students try to select numbers of stones (either 2, 3, or 4) before the opponent makes a pile of 21 stones.

Analysis of the data revealed that students did exhibit identifiable scientific thinking and problem solving skills when interacting with the computer simulation programs. There were nine categories of heuristics identified: trial and error (employed most often at the beginning of a program), working forward, working backward, accounting for all possibilities, looking for a pattern, simplifying a problem, exhaustive listing, working from partial solutions, and breaking set. The students varied greatly in their persistence and ability to cope with ambiguity. In general, the students used an inductive approach rather than a deductive approach. In most cases, they worked forward, that is, they often collected enough data to isolate one variable and once this was accomplished tried to isolate the next variable. Many of the subjects were successful at seeing patterns, looking ahead, and using what they knew to predict results. They often had trouble, however, in organizing and analyzing the data collected during the computer interaction. Students were able to evaluate, revise, and/or abandon nonproductive strategies, although it was not always easy for some subjects to do so. The students varied greatly in their ability to use metacognitive processes to evaluate their own problem-solving strategies.

In a related study, **Horak** (1991) made use of different computer simulations to study students' metacognitive skills. The computer programs employed were (1) Magic Mirrors, (2) Funny Numbers, and (3) Animals. The first program requires the students to find the position and angle of mirrors placed in a 4 x 4 grid. This is done by "shooting" light beams into the grid and finding the position they exit the grid. By analyzing the data they collect, the students can infer the correct placement of the mirrors in the original grid.

The second program requires the subjects to find special fractional numbers that may be reduced by alternative algorithms to yield correct fractions. An example of this is 16/64 which may be reduced correctly by crossing out the 6 in the numerator with the 6 in the denominator. Students are challenged to determine other examples where cancellation properties of this sort may apply.

The third program involves a simulation where students try to feed animals by throwing food over a barrier into their pen. The subjects must determine which angles of throw and what velocity of throw will result in the food entering the pen, by recording the data and systematically revising angles and velocities. The program is made more difficult by the fact that students may use the same angle or velocity only a finite number of times. During each interaction, a record was kept of the students' verbal behavior and computer responses. The data were analyzed using an interaction grid that identified the relevant metacognitive processes.

Horak found that: (1) Overall, subjects varied widely in their ability to choose a course of action. Some subjects would sit and appear to consider what to do before attempting the problem, others would read the directions and immediately start to interact with the computer. This choice of actions did not appear to be connected to the age or ability of the subject. (2) Subjects were more capable of monitoring the outcomes of their decisions when they had had some positive experience with this strategy. Subjects who were successful on a prior task were more willing to think about their actions. (3) Revising strategies was most difficult. Subjects who were successful with one strategy in an initial problem were more inclined to pursue that strategy in a different situation whether or not it yielded useful results. (4) The subjects were not able to prioritize their actions. They chose their initial and many subsequent lines of action based upon incorrect inferences made from the accumulated data.

Rudnitsky and Hunt (1986) conducted a study to examine and describe approaches and strategies used by children to solve a complex problem involving or discovering a set of cause-effect relationships. The students, from grades four through six, were told that a dot of light on the computer represented a vehicle which could be moved by colored keys on the keyboard. The problem was to determine what effect each colored key had on the vehicle. The students had to make two or three keystrokes at a time to cause the vehicle to move; the program would not accept fewer than two or more than three keystrokes. The researchers identified four different types of move sequences:

1. Exploration segments were when the subjects were trying combinations of moves freely, often forgetting or ignoring the built-in restrictions on number of keystrokes.

2. Patterns involved the repetition of a particular two or three keystroke sequence.

3. Focusing appeared to represent a transition and seemed to involve the application of a strategy such as putting together various combinations of keystrokes or pursuing a hunch about the effects of a particular key. Focusing was systematic and often generated information that could be transformed into a theory or testable hypothesis.

4. Hypothesis testing involved making and testing a prediction. Not all hypotheses were perfectly correct or testable and not all hypothesis testing led to a correct, or any, answer. Typically, however, one or two predictions that were borne out constituted sufficient evidence for students to draw conclusions.

The results of this study support the position that theories do not exist in nature, waiting to "be gotten." Rather, theories must be constructed. Thus, if we are to aid students in developing problem-solving skills, we must provide for the kind of theory generating activity implied by these results.

Champagne and Klopfer (1981b) investigated the interaction between semantic knowledge and process skills in eighth-grade students' (n=27) performance in solving two types of problems (analogies and set-membership) of inducing structure drawn from physical geology concepts. It was hypothesized that, with performance adjusted for differences in IQ and science knowledge, (1) students with high ratings in structuring process skills and students with low ratings would perform equally well in solving analogies problems involving the same science concepts, and (2) students with high ratings in structuring process skills would perform better in solving set-membership problems involving the same science concepts than would students with low ratings.

Champagne and Klopfer concluded that, as they had hypothesized, successful performance on analogies problems cannot be attributed to differences in the students' structuring process skills. For set-membership problems, however, students rated high in processing skills performed better in problem solving both before and after instruction, although not in one-year-later comparison.

Finally, **Ronning and McCurdy** (1982) reported on: (1) a study of problem solving processes of 150 junior high school students, and (2) the results of a problem solving processes training program for junior high school students. Each student was given a set of six problems selected to resemble problems found in junior high school science textbooks. Before attempting the problem set, junior high school students in the treatment group were exposed to a four-hour general problem solving program that attempted to develop skills in defining, attacking, and solving science problems. The control group, composed of students from the same junior high school, attempted the problems without the problem solving training program.

No significant grade level differences were found for students in the seventh, eighth, and ninth grades, though there was a trend to higher scores at higher grade levels. Although boys' performances at all grade levels slightly exceeded that of girls, no significant gender differences were found. Junior high school students were found to have a generally approving attitude toward science as interesting and necessary. At the same time, they regarded science as difficult, unimaginative, hard to understand, and requiring much memorization. The "junior high school students evinced not even rudimentary general problem attack skills" (p. 31). The evidence suggested that junior high school students are developmentally unable to profit from a general problem solving strategy. It was further suggested that a hands-on approach to teaching science using tasks to pique the curiosity may help students approach problems more skillfully and to solve them more successfully.

Summary

The evidence suggests that teachers can correctly distinguish between those students with superior problem solving skills and those without. Within the relatively structured settings of the studies reviewed, successful problem solvers

were able to identify the nature of the problem, employ at least some appropriate logical thinking skills, and express their reasoning procedures. Using computer-simulated problems, students quickly developed effective strategies to improve estimation and hypothesis formulation skills. In a similar manner, the generation of hunches in written format seemed to improve students problem solving effectiveness. Performance generally improved with age, which is likely a matter of increased maturation. Performance also improved with increased availability of information because the demand on short term memory was decreased. It should be noted, however, that while performance improved in these cases, the hypotheses that were generated were not necessarily correct or even testable; hypotheses were often based upon insufficient evidence. The case for teaching general problem solving skill fared less well. The evidence suggests that not only do junior high students not have even rudimentary general problem attack skills, it appears that they are not developmentally able to profit from a general problem solving strategy.

Gender Differences Related to Problem Solving

The relationship of gender to problem solving was a major factor in eight studies and was included among other considerations in several other studies.

Graybill (1975) hypothesized that sex differences in intellectual development would become more apparent in the transition from concrete to formal operations and that boys would be more successful than girls in solving selected science problems. The sample consisted of three pairs of boys and girls of 9, 11, 13, and 15 years of age, with the pairs matched as closely as possible with respect to birthdate, IQ, school achievement, and socioeconomic background. Each subject was asked to solve four Piagetian problems (Equal Angles, Floating Bodies, Rods, and Chemical Experiments), and their performance was rated.

It was found that: (1) Girls differed from boys in the point at which they developed logical thinking abilities. Boys began to score at the formal level at 13 years of age while the girls lagged behind. No girls in the sample consistently scored at the formal level. (2) Boys and girls began to show differences in logical thinking ability at about 11 years of age. (3) Boys were more successful than were girls in solving the science problems in this study.

Treagust (1980) investigated whether a relationship existed between performance and gender on six Piagetian-type tasks. The subjects (n=108), equally divided by gender, were selected such that there were 35 students from each of grades 8, 10, and 12. The six tasks presented to the students in random order were: Telephone Poles Task, Rods Task, Water Level Task, Similar Triangles Task, and Model Landscape Task.

It was found that males scored significantly higher than females on four of the tasks. It was suggested that these results, indicating higher spatial abilities for males, may stem from differences in the types of subjects encountered in the school curriculum or that the differences may result from differing rates of development in spatial conceptualization between males and females.

Patterns of similarity and differences related to the solution of science problems by students grouped by gender and spatial ability were investigated by **Camp** (1981). Based on their performance on a spatial relations test, ten ninth graders (total n=40) were selected into each of four groups: high scoring males, low scoring males, high scoring females, and low scoring females. The students were each asked to solve two items from the spatial relations test, a volume displacement puzzle, and two science problems: one involving the earth-sun-moon system and one involving relative motion.

Among other things, Camp found that: (1) more than half the low scoring females had a geocentric model of the universe; (2) high and low scorers (both male and female) thought that the earth's shadow caused the phases of the moon; (3) all of the males did the volume displacement puzzle correctly while less than half of the females did so; and (4) the high scoring males were able to shift planes when diagramming the moon and earth from a point on the moon's orbit while very few females, high and low spatial, were able to correctly diagram this

arrangement. The greatest and most consistent differences occurred between the high scoring males and the low scoring females.

Two questions related to possible gender differences were investigated by **Pirkle and Pallrand** (1989). First, they attempted to determine whether there was a difference in the relative success of males and females when presented with the task of constructing a mental representation of projectile acceleration. Second, they examined what, if any, differences there were in the procedure employed by males and females when moving from an incorrect to a correct response. Ninth graders, 22 females and 18 males, took part in an independent, computer-assisted problem solving activity.

A clinical interview was undertaken with each subject using a protocol designed to allow subjects to predict the path and acceleration of a projectile. The predictions were represented as graphs and were compared to computer representations of the same problem. The results suggested that there was no significant difference in performance between males and females on the flight protocol.

Gender-related differences in the relationship between the development of formal reasoning skills and learning interests of junior high school students was investigated by **Shemesh** (1990). The subjects were 249 students enrolled in three urban schools in Israel. Students were assessed for their level of formal development by a videotaped group test adapted from the Lawson group test of formal operations. The test consisted of 12 tasks, two each from each of the following subscales: conservation of weight and displaced volume, control of variables, proportional reasoning, probabilistic reasoning, combinatorial analysis, and recognizing correlations. Learning interests were assessed by a written response to an open question that asked students to list two subject fields in which they were most interested. Learning interests listed by students were categorized into three groups: (1) science, math, and technology subjects; (2) humanities and social studies; and (3) arts, foreign languages, and physical education.

The findings showed that: (1) There were gender-related differences in the performance of formal reasoning tasks, as measured by the videotaped group test, with boys mastering the quantitative formal operations earlier and to a greater extent than their girl classmates. (2) There were gender-related differences in declared learning interests with a general tendency of boys toward science, math, and technology and the girls showing a tendency toward social studies and humanities. (3) No gender-related differences were found in the overall relation between learning interest and cognitive development. Interest in science, math, and technology was positively correlated with the development of formal reasoning skills in both genders.

The effect of group size (individuals, pairs, and quads of students), gender, and ability grouping (high, medium, and low), on student achievement in an environment using microcomputers as tools in learning science process skills was studied by **Berge** (1990). Seventh and eighth grade students (n=245) selected from twelve classrooms in three schools participated in the study. The TIPS and

a researcher-developed test closely matching the style and format of the practice that the students had experienced during the intervention were administered as pre- and posttests. The only statistically significant result was a main effect on ability for means on both tests; there was no significant effect for gender or for group size.

Berge concluded that: (1) teams of two and four members working together solved problems as effectively as did individuals, (2) the lessons and procedures implemented in the study generated gender-neutral activities in science, and (3) the microcomputer can be used as a tool to promote student learning of science process skills.

Squires (1977) analyzed sex differences and cognitive styles (field-dependent/independent) of 13 year-olds in science problem solving situations. Two groups of eighth grade students were used in the study, 32 from a parochial school (16 males, 16 females) and 62 from a public middle school (27 males, 35 females). Cognitive style was determined by use of the Hidden Figures Test and problem solving was measured by released items of the National Assessment science instrument. Among other things, it was found that: (1) females scored higher than did males on problem solving; (2) field-independent students scored higher on problem solving than did field-dependent students; and (3) IQ and reading ability both correlated significantly with problem solving. On the basis of other research indicating that girls' verbal skills are generally better than boys' skills at this age, Squires concluded that verbal skill (reading ability) was the basis for the higher scores exhibited by girls in this study, which involved verbal problem solving.

In discussing the U. S. results of the Second IEA Science Study (SISS), **Humrich** (1988) noted that sex differences, favoring males, were found at every grade level and in every subject area in the written science achievement tests. There are, however, some encouraging findings in the manipulative tests of process skills which were administered to both fifth (n=2839) and ninth grade (n=2519) students in the U. S.

For fifth grade students there was no significant difference between boys' and girls' scores on either subtest. At the ninth grade level, there was a 3% difference favoring boys on one subtest and no difference on the other subtest. Performance on some of the individual tasks varied. Generally, boys did better on tasks with a physical science content and girls did better on tasks involving life sciences examples (**Kanis, Doran and Jacobson**, 1990). Humrich suggests that perhaps process skills are not quite so sex-role stereotyped as is content. The testing was conducted individually, possibly allowing girls to feel freer to indulge in risk-taking. A further suggestion is that teaching science in an integrated, process-oriented manner may be more a equitable approach.

Studies that included gender as a factor, but not a major emphasis, in problem solving reported mostly nonsignificant differences. **Schmeiss** (1970) found no significant difference in sixth grade boys' and girls' ability to solve selected science problems or in solving new science problems. **Linn and Levine** (1976) found no significant consistent sex difference in ability to control variables.

Ronning and McCurdy (1982) and **Ronning, McCurdy and Ballinger** (1984) found no significant gender differences in junior high school students' problem solving abilities. In a study involving word problems, **Egolf** (1979) found that gender was not related to problem solving ability. In a survey of North Carolina students, **Coble** (1986), **Spooner** (1986), and **Mattheis, Coble and Spooner** (1986) reported no significant difference in the scores of males and females on TIPS II. In a series of studies, **Bitner-Corvin** (1987, 1988a, 1989) found no significant gender differences in total scores on the GALT, though there were some differences on some subscales.

Summary

The research on gender related differences in problem solving in middle/junior high school science has produced mixed results. There is some evidence to suggest that boys do better than girls at tasks involving spatial relations. Conversely, the evidence suggests that girls do better than boys at tasks involving verbal problems. It not clear, however, whether these differences stem from differences in past experiences, differences in the types of subjects taken in the curriculum, or from differing rates of development in spatial and/or verbal skills. The majority of the studies indicated no significant gender differences in problem solving abilities or in logical thinking as measured by TOLT and GALT.

When manipulative tests of science process skills were used, as in the Second IEA Science Study, girls and boys did equally well. It does appear that girls are more interested in and do better on tasks involving life sciences while boys do better and are more interested in the physical sciences.

Cognitive Style and Problem Solving

Six investigations focused on students' cognitive styles or preferences in relationship to problem solving. In addition, two other studies included cognitive style as an element of interest.

Ronning, McCurdy, and Ballinger (1984) assert that a viable theory of problem solving must consider at least three dimensions: domain knowledge, problem-solving methods, and characteristics of problem solvers. Therefore, they selected a single characteristic and examined the relationship of problem solving success and field-independence/field-dependence of junior high school students (n=150). Five females and five males were randomly selected from each of three grades of five randomly selected junior high schools. The *Group Embedded Figures Test* (GEFT) was used as the measure of field independence, and problem solving protocols were analyzed for six science problems presented to the students.

It was found that (1) junior high school students have difficulty with problem solving, especially with problems involving proportional reasoning or separation and control of variables; (2) field-independent students significantly out-performed field-dependent students on the problems; and (3) there was no sex difference for problem solving.

Based on research evidence that novice and expert problem solvers represent and organize knowledge differently, **Pirkle and Pallrand** (1988) examined the way in which field dependence/field independence affected information perception and processing of junior high school students (n=39). The study employed a protocol that elicited from the subjects: (1) their intuitive mental models of horizontal, vertical, and projectile motion; (2) their intermediate mental models of projectile motion; and (3) their post-experimental models of projectile motion. The students, identified as either field-dependent or field-independent by means of the GEFT, were individually questioned about their understanding of the effect of gravity on vertical, horizontal, and projectile motion. They were then given the opportunity to compare or verify their responses with information presented graphically on a computer monitor.

It was found that erroneous intuitive knowledge representation tended to persist for some subjects after information to the contrary was graphically presented on the computer monitor. The results indicated that the field-independent subjects experienced greater success in solving the problems presented than did the relatively field-dependent adolescents in the study.

Lawson and Wollman (1977) involved 54 sixth graders (28 males, 26 females) in a study to answer three questions: (1) What is the relationship between subject performance on Inhelder and Piaget's bending rods and balancing beam tasks? (2) What is the relationship between performance on these tasks and ability to make critical value judgments in social contexts? (3) What is the relationship between these abilities and degree of field-dependence/ field-independence (measured by the GEFT)?

Lawson and Wollman found that: (1) the bending rods and balance beam tasks were significantly correlated; (2) the tasks were significantly correlated with the value questions; and (3) high correlations were found between the GEFT and the bending rods and balance beam tasks. The authors suggest that the high correlation between scores on the bending rods and balance beam tasks supports the Piagetian position that these tasks measure the same psychological parameters, and that the ability to successfully abstract formal reasoning patterns from their concrete content seems to be restricted by the same factors responsible for a high degree of field dependence. This finding is consistent with other studies where degree of field independence has been shown to correlate highly with success on certain types of problems.

The authors indicate that these findings imply that if we wish to enhance success in problem solving, science instruction should attempt to foster autonomy by allowing students to freely investigate phenomena. Inquiry-discovery methods that allow students autonomy and initiative may foster field independence and, therefore, cognitive development. Science classrooms should thus provide a variety of increasingly complex and repeated experiences. It appears likely that such experiences will occur most readily when students investigate real science phenomena with direct, hands-on activities.

Two other studies (described in more detail elsewhere in this summary) included field dependence/independence as factors. **Squires** (1977) analyzed sex differences and cognitive styles (field-dependent/independent) of 13 year-olds in science problem solving situations and found that field-independent students scored higher on problem solving than did field-dependent students. **Stuessy** (1988), in constructing a model for the development of reasoning ability in adolescents, found a significant direct effect of field dependence/independence and an indirect effect of locus of control through the field dependence/independence variable on scientific reasoning.

In a five-year study, **Scott** (1973) examined the longitudinal effects of the inquiry strategy method on students' styles of categorization. Ninety-two students were included in the study; 42 (experimentals) received two to three years of inquiry strategy exposure in their science classes during their later elementary or junior high school years while the remaining 50 (comparisons) received conventional science teaching during the course of their elementary, junior, and senior high school years. The longitudinal groups (16 experimentals and 16 comparisons) were tested twice, once in 1966 when the students were ending seventh grade and again in 1971, prior to graduation from high school.

The results of the longitudinal testing indicated that the inquiry process had a persistent enough effect on students' analytical behavior that a significant advantage over the comparison students was maintained for six years.

The influence of the reflective/impulsive dimension on problem solving skills was investigated by **Jacknicke and Pearson** (1979). Of the 184 sixth graders involved, 68 were classified as reflective in disposition, 70 as impulsive, and the remainder as being neither reflective nor impulsive. The problem solving

tasks required either a guided-discovery approach or an open-ended approach for completion.

Analysis of the data showed that: (1) Reflectives and Impulsives performed about equally well in selecting and generating observations and hypotheses and in evaluating these observations and hypotheses. (2) Reflectives and Impulsives asked similar types and quantities of questions during the problem solving process. (3) Reflectives' performance was superior to that of the Impulsives in selecting and generating hypotheses with content and modes of presentation different from those in the guided-discovery and open-ended tasks. (4) **Gagne's** (1965) claim that observing and hypothesizing abilities exhibit high inter-task generality was only partially supported by this study (that is, the abilities appear to be more task-specific than Gagne suggests).

Dunlop and Fazio (1975) studied abstract preferences in problem solving tasks and their relationship to abstract ability and formal thought. An assumption underlying this study was that the level of abstract reasoning used by a student when solving problems is often substantially below the student's capacity. Three hundred twenty-nine randomly selected students from grades 8, 9, 12, 13, and 16 were given the *Shipley Test of Abstract Reasoning*. All students were presented with 18 written problem solving tasks and asked to state their preferences concerning methods for arriving at a solution for the tasks.

It was found that, as expected, older groups demonstrated greater abstract reasoning ability as well as a greater percentage of students in the formal operational stage of development; however, no significant differences were found between grade levels with respect to abstract preference scores. This preference was found to be independent of abstraction ability and the development of formal operational thought. The results supported the conclusion that an individual's preference for a concrete algorithm to a problem solving situation was not dependent upon his or her abstraction ability. No significant correlations were found between abstract reasoning ability and abstract preference, further supporting the independence of these two variables. The assumption that a student's level of reasoning is often below his capacity is supported by the results of this study; that is, a student's preference toward a specific solution may be partly responsible for his below-capacity functioning.

Summary

It is apparent from the evidence that middle/junior high school students find problem solving difficult. This is particularly true when the problems involve separation and control of variables. The research on cognitive style also clearly indicates that middle/junior high school students who are field-independent enjoy a significant advantage over field-dependent students in solving science problems. A comparison of students characterized as reflective or impulsive indicates no significant difference in their ability to solve problems; however, the reflective students appeared to be better able to transfer their skills so long as the

new problems were not too different from the familiar problems. Although students' abstract reasoning ability appears to increase, within limits, with age, a student's preference for a concrete approach to problem solving may result in below-capacity reasoning. Finally, the impact of inquiry strategy on student analytical behavior seems to have long term effects, with benefits persisting for at least six years.

Cognitive Development and Reasoning Ability

Several studies examined various aspects of reasoning ability and its relationship to cognitive development. As can be seen, reasoning is usually considered to include such skills as identifying and controlling variables, interpreting data, and hypothesizing—skills that are also related to problem solving.

Linn and Levine (1976) conducted an investigation of the developmental ability to control variables by students from a large comprehensive school in a middle class suburban area of London. The sample (n=120) was composed of 40 students, half females and half males, from each of three age groups: 12, 14, and 16 year-olds. Physics problems involving either familiar or unfamiliar variables were presented to the students in three different informational formats. Success (meaning that the subjects understood that all but one variable must be controlled before the effects of that variable could be assessed) on the problems ranged from 5% to 95%.

It was found that (1) there were no consistent sex differences across problems for any question; (2) both familiarity with the variable and format of the question influenced success; and (3) there was a qualitative change in ability to control variables between ages 12 and 16. The investigators concluded that there was some evidence to support the hypothesis that subjects try to solve new problems by drawing upon apparently relevant past experience.

The effects of problem format and number of independent variables in the problem on the responses of eighth grade students (n=548) to a control of variables reasoning task (the Bending Rods Task) was investigated by **Staver** (1986). The number of independent variables refers to the number of ways in which the rods differed. The problem was administered in 2-variable (thickness, materials), 3-variable (thickness, materials, amount of weight), 4-variable (thickness, materials, amount of weight, length), and 5-variable (thickness, materials, amount of weight, length, cross-sectional shape of rods) forms. Initial analysis indicated that four separate levels of the independent variables were unnecessary, and the data were pooled to give two distinct levels (2-3 variables and 4-5 variables). The task was presented in two separate formats: (1) completion answer followed by essay justification; and (2) completion answer followed by multiple-choice justification. One (1) point was awarded for responses that included the correct choice of rods and a justification indicating that control of variables reasoning was employed to obtain the answer. Zero (0) points were given for all other responses. The results showed that:

1. task format had no effect on subject's scores;

2. the differences between subjects' mean scores on the 2-3-variable essay versions and the 4-5-variable essay versions were significantly greater than the mean scores of the corresponding multiple choice versions of the task, which exhibited rather uniform scores; and

3. the 2-3-variable forms together were significantly less difficult than were the 4-5-variable forms together.

The knowledge and procedures used by the students to solve the tasks are contained in working memory. The results of this study indicate that adding independent variables to a control of variables reasoning problem leads to an overload of working memory, which in turn affects performance. The results also suggest that the effect of format on reasoning assessment is connected to the degree of working memory overload that occurs during such evaluation. Science teachers must pay close attention to the demands placed on working memory during both instruction and evaluation.

The purpose of a study by **Saunders and Jesunathadas** (1988) was to examine the effect of familiar and unfamiliar task content upon the proportional reasoning abilities of ninth grade students (n=96). The major concern was: Do students' problem-solving abilities generalize across specific subject matter domains? A written-response group test was constructed consisting of 22 items: 12 were word problems which required proportional reasoning, 5 were word problems which contained real-number constants and a real-number unknown but which did not require proportional reasoning, and 5 were computational items.

The researchers found that student performance was higher on proportional reasoning problems involving familiar content than with unfamiliar content, but that content familiarity interacted with difficulty. When the proportional reasoning problems involved simple ratios, the mean score with familiar content was greater than with unfamiliar content. But when the problems involved difficult ratios, the familiarity with content did not have a significant effect on the students' achievement at solving problems. When level of difficulty was considered separately, the students' mean score for problems with simple ratios was significantly higher than their scores for problems with difficult ratios. The results for gender (independent of content familiarity and level of difficulty) showed that the mean score of male students was significantly higher than that of female students.

Recognizing that proportionality is one of the most ancient and fundamental connections between mathematics and science, **Heller et al.** (1989) investigated the effects of two context variables, ratio type and problem setting, on the performance of seventh grade students (n=254) on a qualitative and numerical proportional reasoning task. The students were given proportional reasoning problems that varied on each of the variables, an assessment of qualitative/quantitative reasoning, and a rational numbers test.

Analysis of the data indicated that qualitative reasoning is a necessary but not sufficient condition for success on proportional reasoning problems. Some student success with proportional reasoning could be attributed to memorization of procedures and skill with rational numbers even in the absence of quantitative reasoning skills. Some students were also successful on proportional reasoning

skills even though they lacked skill in rational numbers, but skill with rational numbers insured success in proportional reasoning. A hierarchy of difficulty for problem settings was found with the least familiar being the most difficult and the most familiar being the least difficult. The problem dealing with fuel consumption of furnaces was more difficult than the problem dealing with speed. Both the fuel consumption and speed problems were more difficult than the problem dealing with buying gum, for both proportional and qualitative reasoning. Differences in ratio type were larger when the problems were in unfamiliar contexts.

Bady (1977) studied the logical reasoning ability of 55 male students, 20 of whom were ninth graders, 20 were eleventh graders, and 15 were college freshmen. Three tasks were presented in clinical interviews to investigate adolescents' ability to see correlations in data and to test hypotheses. One task was to determine if the student tested a hypothesis by finding confirming instances or, logically, by finding the disconfirming instance. Two tasks asked the student to find a relationship between two variables.

Significant differences in scores were found for each task across age; however, the scores were relatively low in general. The results indicated that logical reasoning abilities develop with age, but that the students frequently lacked the ability to deal with correlated data in problems.

A series of four investigations into patterns of reasoning was documented in a set of four related reports. **Capie, Newton and Tobin** (1981) attempted to determine if developmental patterns in the ability to control variables: (1) could be identified in a large, diverse sample; (2) were similar regardless of problem context; and (3) were similar for subjects of similar developmental levels regardless of educational level. Data from 2282 subjects in grades 6-13 were collected using the TOLT. The controlling variables problem in TOLT Form A involves two problems dealing with pendula; Form B involves two problems with rolling cylinders down inclined planes. One question requires the student to vary the weight; another requires that it be held constant. To get the correct answer, students must choose one of five sets of apparatus for their experiment and choose a justification for their choice from among five alternatives.

Four common response patterns were found to occur for each item: (1) correct response and correct reason; (2) testing all possibilities without controlling variables; (3) testing extreme examples (such as the longest and shortest) without controlling variables; and (4) testing all possibilities despite recognizing that a variable should be held constant. In all four problems, substantial numbers of concrete thinkers (low TOLT scorers) chose to test all possibilities or the two extremes. It was not clear whether focusing on the two extremes or all possible examples is the first step in emergence of controlling variables. In general, the proportion of correct responses increased consistently at all developmental levels. The response patterns for transitional and early formal subjects were similar regardless of educational level, suggesting that inadequate reasoning patterns are similar among students of all educational levels.

McKenzie and Padilla (1981) attempted to determine if developmental patterns in correlational reasoning: (1) could be identified in a large, diverse sample; (2) were similar regardless of problem context; and (3) were similar for subjects of similar developmental levels regardless of educational level. Data from 2282 subjects in grades 6-13 were collected using two parallel forms of the TOLT. Each item consisted of two questions. One asked the student to decide whether a correlation existed between two attributes of an object (i.e., between the size of mice and the color of their tails). The second asked the student to choose a justification, from among five, that explained the selected answer.

Four common response patterns (three incorrect and one correct) were found for each item: (A) no relation among different variables was considered in the justification; (B) only two values of the attributes were considered in the justification; (C) all four values of the attributes were considered to make two comparisons; and (D) a quantitative comparison using all four attributes was used to correctly solve the problem. The predominant response of concrete thinkers was A, which was thought to be early concrete in nature. For transitional students, a shift in responses toward more adequate, but still incorrect responses (B and C), and toward the correct response was evident. Formal thinking students primarily gave the correct response. Although college students performed better than high school students, and high school better than middle school students, response patterns were more predictable and stable across developmental level than educational level. Thus, concrete students tended to respond in the same ways regardless of educational level.

Newton, Capie and Tobin (1981) attempted to determine if developmental patterns in proportional reasoning: (1) were similar regardless of problem context; and (2) were similar regardless of educational level. Data from 2282 subjects in grades 6-13 were collected using the TOLT. In the TOLT subjects are presented two problems requiring proportional reasoning. The two problems differ both quantitatively and qualitatively. The subjects are required to select the best answer from five choices and to identify their reason from five alternatives. The data were examined for subjects who had been categorized in three ways: (1) by TOLT scores, (2) by educational level, and (3) by developmental level within each educational level.

The four most common responses, in order of frequency, were: (1) correct answer and correct reason; (2) focus on a single difference (additive thinking); (3) there is no way to predict; and (4) correct reason but with an arithmetically incorrect answer (i.e., 9 instead of 8 2/3). In general, the observed patterns of reasoning were similar regardless of developmental level, educational level, or problem context. Large portions of the students did not solve these problems. The incorrect responses suggest emerging developmental patterns. The mode of reasoning just prior to the development of proportionality was clearly additive, and the patterns were similar across the problems studied.

Tobin, Capie and Newton (1981) attempted to determine if developmental patterns of probabilistic reasoning: (1) could be confirmed using a large, diverse

sample of subjects; (2) were similar despite variations in the complexity of the reasoning required to solve a problem; (3) could be determined if variations in problem context led to variations in response patterns; and (4) were similar for subjects of similar formal reasoning ability regardless of educational level. Data from 2282 subjects in grades 6-13 were collected using two forms of the TOLT. In each form of the TOLT subjects are presented two problems requiring probabilistic reasoning. The subjects are required to select the best answer from five choices and to identify their reason from five alternatives. The proportion of students obtaining a correct response was linearly related to formal reasoning ability.

Two common approaches were identified for individuals attempting to use probabilistic reasoning to solve problems. The two problems that tended to occur were: (1) subjects considered the entire set of objects but did not consider the effects of multiple elements from the favorable outcomes set; or (2) subjects only considered selection from the favorable outcome set and ignored the presence of other sets of objects. Similar response patterns were evident in items requiring simple or complex reasoning. Similar response patterns were provided by subjects at each educational level.

The relationship between integrated process skill and formal thinking abilities of middle and high school students (n=492) was examined by **Padilla, Okey, and Dillashaw** (1983). Approximately 80 students from each of the seventh through twelfth grades were selected to provide a full range of ability levels. The Test of Integrated Process Skills (TIPS), a multiple choice instrument of 36 items, was used to measure the five integrated skills of hypothesizing, identifying variables, operationally defining, designing an investigation, and graphing and interpreting data. Formal thinking ability was measured by the *Test of Logical Thinking* (TOLT), a ten-item test measuring five modes of logical thinking—identifying and controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning.

Correlational analysis showed a strong relationship (r=0.73) between achievement on the two measures and all subtests of the measures; factor analysis data corroborated the correlational evidence. The evidence thus shows that science process skill ability is strongly associated with logical thinking. Further research is needed to determine whether process skill ability influences logical thinking ability, or whether the converse is the case, and to determine whether teaching for one kind of ability will have an effect on the other.

Shepardson (1991) observed eighth-grade life science students to determine what relationships exist among problem solving, student interactions, and thinking skills. The Search, Solve, Create, and Share (SSCS) problem solving model of instruction was used. The students (n=42) were observed in five different SSCS problem solving activities throughout the academic year. Students were observed for their interactions (student and teacher), thinking skills exhibited, and the problem solving phase.

The descriptive statistics imply that half of the students failed to actively engage in all aspects of problem solving or to use a variety of thinking skills to solve problems. It appeared that most students engaged in the data-collecting phase and exhibited information-gathering skills. Half of the students did not exhibit focusing, remembering, generating, integrating, or evaluating skills.

The results suggest that most students did not exhibit higher-order thinking. For the most part, those students who engaged in problem solving and who used thinking skills did so in isolation from the other students or the teacher. For those students who engaged in problem solving and who exhibited the use of thinking skills, the problem solving phase had a greater influence on their use of thinking skills than did student-student or teacher-student interactions. Student-student interactions, however, did foster the use of thinking skills that may not have otherwise been used. Neither the student-student nor teacher-student interactions resulted in the use of a variety of thinking skills; there was a tendency to emphasize the lower level thinking skills (focusing and information gathering). The findings suggest that if student interactions are to enhance the use of thinking skills by students, the use of thinking skills must be made explicit to the students in the context of solving the problem.

The *Burney Logical Reasoning Test* and the Science subtest of the *Stanford Achievement Test* were used by **Dozier** (1986) to investigate the relationships between objective measures of logical reasoning abilities and science achievement. All students in seventh grade life science (n=39), eighth grade general science (n=35), and ninth grade physical science (n=33) classes were tested with both instruments. Significant correlations were found between the sets of raw scores for the seventh grade (r=.541), eighth grade (r=.702), and ninth grade (r=.386); for total population raw scores, r=.553. The author concluded that a significant relationship existed between the objective measures of logical reasoning abilities and science achievement.

A series of studies of logical reasoning abilities of students was conducted by Bitner. In the first of these (**Bitner-Corvin**, 1987) she evaluated a convenience sample of all seventh through twelfth graders (n=156) in a consolidated school district in Arkansas. Four questions were investigated: (1) What percentage of the students are formal operational thinkers as measured by the GALT? (2) Are there significant differences in the level of thinking among seventh through twelfth graders? (3) Are there gender differences in the level of thinking? (4) What are the underlying differences among the students classified as formal, transitional, or concrete operational?

The percentages of each reasoning level for the total sample were 11% formal, 19% transitional, and 70% concrete, with the trend to higher levels of reasoning corresponding, roughly, with grade level. Significant gender differences were found for individual items on the GALT, but no significant gender difference was found for the total.

A second study (**Bitner-Corvin**, 1988b) investigated the logical and critical thinking abilities of sixth through twelfth graders (n=173) to determine whether

logical thinking abilities were predictors of critical thinking abilities and academic achievement. The instruments administered were the (1) GALT, (2) *Watson-Glaser Critical Thinking Appraisal*, (3) *Ross Test of Higher Cognitive Abilities*, (4) SRA, and (5) MAT6.

No significant gender differences were found for the total scores on the GALT, Ross, and Watson-Glaser; however, a significant difference in favor of males was found for probabilistic reasoning on the GALT. The five formal reasoning modes on the GALT were predictors of critical thinking as measured by the Ross and Watson-Glaser. Also, the formal operational modes on the GALT were significant predictors of academic achievement. The results of the study indicated that a significant percentage of students in grades six through twelve were neither logical nor critical thinkers.

In another study (**Bitner**, 1989) to investigate the develop-mental patterns of logical reasoning of students (n=84) in grades six through ten, the GALT was administered three times over a span of 20 months. Correlational reasoning was found to be the most difficult for the total sample for the three administrations. No significant gender differences were found. An ANOVA (GALT score by grade level) was significant for each test administration.

The results indicate that: (1) the majority of students were not functioning at the formal operational reasoning level; (2) a significant movement from concrete to transitional operational reasoning occurred at the end of grade seven; and (3) a plateau effect occurred between grades eight and nine.

A fourth study (**Bitner**, 1990) was to investigate the effect of an eclectic thinking processes model on the logical reasoning abilities of students in grades six through twelve. The experimental school had 159 students, the control school, 111 students. The thinking processes model incorporated logical, critical, and creative thinking skills. Teachers in the experimental school were presented with the model in workshops during the summers of 1986 and 1987 and encouraged to infuse the thinking processes into the mandated curricula during the 1986-87 school year, and expected to do so during 1987-88. The control district neither participated in the workshops nor was expected to infuse the thinking processes into the mandated curricula. The GALT was administered to students in both schools as a posttest. For both experimental and control schools, correlational reasoning followed by probabilistic reasoning was the most difficult. Students in the experimental school performed significantly higher than students in the control school in controlling variables, correlational reasoning, and total GALT score. Classification of students according to reasoning levels indicated that only 3% of the total sample performed at the operational reasoning level. The significant differences favoring the experimental school seemed to indicate that the eclectic thinking processes model was effective.

A comparison study involving junior high school students (Grades 7, 8, and 9) in North Carolina and Japan was reported by **Coble** (1986), **Spooner** (1986), **Mattheis, Coble and Spooner** (1986), and **Mattheis et al.** (1992). The research questions were to compare junior high school students in North Carolina and

Japan in (1) logical thinking skills, (2) integrated science process skills, and (3) to determine the relationship between the logical thinking skills and the integrated science process skills for the two samples of students. Student attitudes toward science were also assessed. A total of 3,291 students in North Carolina and 4,397 Japanese students participated in the study, with an effort made to obtain a typical cross-section of students in both samples (Mattheis et al., 1992). Instruments used were the Attitude Toward Science Scale (ATSS), the GALT, and the TIPS II.

It was found that the North Carolina students had more positive attitudes toward science than did their Japanese counterparts at all grade levels, but there was a decrease in scores from the seventh to the ninth grade (Coble, 1986). Comparison of mean scores for the GALT and the TIPS II indicated that the Japanese students scored appreciably higher on each test at all grade levels. Differences in mean scores by gender were not of practical significance for either sample. Both the Japanese and North Carolina students showed significant improvement in scores on both GALT and TIPS II as they progressed from the seventh to the ninth grade. However, the differences in means on both tests for the two samples was very large at the seventh grade level. This finding suggests that the Japanese students enter seventh grade with a decided advantage in respect to these skills.

Results from the GALT test indicated that only 10% of the North Carolina students were functioning at the formal operational stage while 32% of the Japanese students were functioning in the formal mode (Spooner, 1986). Whether these differences result from school experience or from cultural factors is not known. A moderately strong and almost identical correlation was found between reasoning skills as measured by the GALT test and integrated process skills as measured by the TIPS II for each sample. The North Carolina and Japan correlation coefficients were 0.63 and 0.64, respectively. It was noted that the two large samples had significantly different test scores, yet had nearly identical correlations between the tests. It was suggested that these results imply a high relationship between reasoning and process skills for junior high students, that the details of this relationship are not understood (Mattheis et al., 1992).

Stuessy (1988) developed and tested a model for the development of reasoning abilities in adolescents. A battery of assessments for locus of control, field dependence/independence, IQ, rigidity/flexibility, and reasoning was given to middle school (n=101) and high school (n=89) students. Student characteristics of age, gender, and experience with science-related activities were also included. The model was tested and revised using path analysis. Significant path coefficients were found for age (.54), experience (.11), IQ (.49), and field dependence/independence (.15), directly to scientific reasoning. A path from locus of control (.29) through field dependence/independence to reasoning was also significant. These five variables accounted for 61% of the variance in scientific reasoning abilities.

Support for an indirect effect of locus of control upon scientific reasoning through the field dependence/independence variable suggests that experiences that encourage a shift from external toward internal locus of control may ultimately affect the development of scientific reasoning abilities. Support for the strong direct effects of I.Q. and field dependence/independence on scientific reasoning suggests individualizing instruction as a way to meet the individual needs of children exhibiting differences in aptitudes and abilities. Finally, this study supported the increase of scientific reasoning abilities with age. Age, in fact, was the strongest predictor of scientific reasoning in the model, with I.Q. being the other strong predictor. This suggests that acquisition of scientific reasoning abilities in adolescents is a developmentally complex process.

A study to search for a learning hierarchy among skills comprising formal operations and the integrated science process skills was reported by **Yeany, Yap, and Padilla** (1986). Ordering theoretic and probabilistic latent structure analysis methods were used to analyze data on five process skills and six logical thinking skills. Intact classes including 741 science students in grades 7 to 12 from 3 schools participated in the study. The GALT was used to measure the performance of students on the six Piagetian cognitive modes: conservation reasoning, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. The TIPS II was used to measure student performance on the five integrated process skills: identifying variables, identifying hypotheses, operational defining, designing experiments, and graphing and interpreting data.

The data analysis indicated that the skills of conservation reasoning, combinatorial reasoning, and design experiments formed the base of the hierarchy. That is, students who had mastered these skills were more likely to be the ones who had the skills which reside at the next higher level. At the next level were found the skills of graphing and interpreting data, operationally defining, controlling variables, and propositional reasoning. These skills appeared to be superordinate to the three skills at the base and subordinate to the remaining four skills.

After the second level, the hierarchical relationships became more complex. Proportional reasoning was prerequisite to probabilistic reasoning which in turn was prerequisite to both correlational reasoning and identifying variables. Identifying variables had the most complex set of underlying prerequisite skills. In addition to having probabilistic reasoning, most students who had the skill in identifying variables had also acquired the skills of hypothesizing, graphing and interpreting data as well as operationally defining. Thus, the integrated process skills appear inextricably entangled with the Piagetian modes of reasoning. Students may not be able to acquire certain scientific process abilities until prerequisite cognitive skills are developed. For example, according to the results of this study, the probability of a student being able to formulate hypotheses before the abilities to conserve, use proportional reasoning, control variables, and use combinatorial logic develop is quite low. This implies that process skill-based curriculum activities need to be developed and presented with a structure that reflects the superordinate and subordinate relationships of the skills.

Two reports summarized research related to reasoning ability, particularly that ability implied by formal thought, which is the ability to apply principles of problem solving to any problem. **Linn and Levine** (1977) reviewed the research on scientific reasoning and found that changes did take place during adolescence but that these changes were not as complete as suggested by earlier descriptions of formal thought. They found that performance related to scientific reasoning appeared to be influenced by (1) the number of variables to be considered, (2) familiarity of the variables to the student, (3) previous experience with variables, (4) method of presenting information about the task, (5) procedure for interacting with the apparatus (e.g., free or constrained), and (6) subject matter of the problem (e.g., physics, biology, etc.).

Of importance for instruction were the findings that (1) only a small number of adolescents could effectively control variables in familiar situations; (2) relatively few adolescents reach the level of formal operations; hence, concrete experience is a valuable aid to learning at all stages of adolescence; (3) programs that offer a choice of mode of learning or which provide several approaches for teaching a principle are probably more useful than programs that adhere to a particular theory; (4) programs that encourage learners to manipulate materials have great potential benefit; and (5) the method that learners use to organize information is important; emphasis should be placed on solution strategies that optimize the organization of the problem.

Staver (1984) examined research on formal reasoning patterns in science education to identify implications for science teachers. The research evidence suggests that: (1) Adolescents and young adults quite frequently do not use formal reasoning patterns when such thinking is needed to fully comprehend a segment of learning. (2) An adolescent may utilize control-of-variables reasoning on one task before another; a second student may reverse the order of tasks. (3) Achievement in science includes both conceptual knowledge and reasoning skills. (4) The conclusion that children are unable to comprehend certain concepts until they reach a certain stage in their reasoning development overlooks the idea (called constructivism) that knowledge may be acquired by formation within the brain through interactions with the environment as opposed to the view that the knowledge is internalized from the outside environment (an empiricist model). In the first case, physical knowledge (size, shape, color of an object) is present in the environment and can be acquired through observation. In the second case, if a child is given a red ball and a blue ball, they are observable. Their difference, however, is not. "The difference is a relationship, mentally constructed from within by the mind" (p. 579). Concepts of the first kind can be successfully taught by direct transmission (telling). Concepts involving relationships, however, require instructional activities that facilitate construction from within and that include concrete models, materials, inquiry, and discussion during the learning process. (5) Science teachers should design and carry out instruction that does not overtax working memory. These situations should involve cognitive conflicts in which difficulty is controlled and success is virtually assured at frequent points.

This can be accomplished by minimizing the number of items of information, maximizing familiarity of information, and highlighting cues.

Summary

The evidence strongly associates science process skills with logical thinking. It also indicates that both cognitive development and problem solving skills are related to maturation. The ability to control variables tends to increase (within limits) with age; however, control of variables may vary from one student to another and from one task to another by the same student.

Most adolescents do not operate at the formal operations level. If we are to maximize opportunities for both cognitive development and problem solving, we need to limit the number of variables involved in problems, to draw upon familiar examples when possible, and to allow freedom of interaction with equipment and materials in direct, concrete, hands-on experience.

Problem Solving and Instruction

The largest segment of the research dealing with problem solving in middle school science is related to the effects of various aspects of instruction on students' problem solving ability.

Bowyer, Chen, and Thier (1976) studied the effects of a free-choice environment on sixth graders' (n=90) ability to control variables. Half of the students were randomly assigned to a treatment group that had access to a Science Enrichment Center in which they could select a science activity of their choice along with their choice of materials.

It was found that: (1) more than 60% of the students within all subgroups did not control variables; less than 32% controlled variables inconsistently; and an insignificant number controlled consistently; and (2) the experimental group differed significantly from the control group. The program resulted in transferring approximately one third of the experimental population from a state in which they were unable to recognize the need for controlling variables to one in which they recognized the necessity to control experiments. Seventy-eight percent of the experimental group understood the necessity for controlling variables, particularly when the variables were familiar ones such as weight and length.

McKee (1977) investigated the effects of two contrasting teacher behavioral patterns on science achievement, problem solving ability, confidence, and classroom behavior for students in sixth grade science. The teaching patterns were student-structured learning in science (SSLS), which minimized restrictions on students, and teacher-structured learning in science (TSLS), which was moderately restrictive. One hundred students in four classes were given a fifteen-week treatment period at the end of which each student was individually given a problem solving and confidence interview. Data on student sex, ethnicity, and IQ were compiled.

Results of the data analysis indicated that: (1) SSLS students performed significantly better on problem solving tasks; (2) SSLS students had significantly higher confidence levels; (3) black students in SSLS classes performed better on problem solving tasks than did black students in TSLS classes; (4) black male students in SSLS classes performed better on problem solving tasks than did other groups, while black males in TSLS classes showed the lowest performance; black females in SSLS classes performed better than did black females in TSLS classes; and (5) significant correlations were found for problem solving ability and confidence level, for problem solving ability and IQ, and for confidence level and IQ. McKee concluded that the SSLS strategy functioned better to improve problem solving skills of black students while working just as well for white students, and that the SSLS strategy was the obvious choice for teachers interested in promoting a student's ability to solve problems while improving self-confidence.

Creativity and the group problem solving process was studied by **Foster** (1982) to determine whether cooperative small groups would stimulate the

creativity of fifth and sixth grade students (n=111) more than would an individualized learning environment. Creativity was defined as becoming sensitive to problems, identifying the difficulty, searching for solutions, testing and retesting hypotheses, and communicating the results. Half of the population (control) worked by themselves, while the other half (experimental) worked together in groups of four or five. Each half worked in a student-structured environment on the same science activity, which involved creating as many different types of electrical circuits as possible from a given set of batteries and bulbs. The same trained teacher guided students in both the individual and small group settings.

Among other things, it was found that both fifth and sixth graders in small groups did significantly better on creating electrical circuits than did individuals working alone. Understanding of electrical circuits was not differentially affected by the treatment conditions, though the scores indicated that both groups of students had a better understanding of electrical circuits from being in the study than from previous experience. Analysis by gender indicated that boys did better in the experimental group situation while girls did better in the control group situation. Foster concluded that, for fifth and sixth grade students, working within cooperative small groups was more effective than working alone.

A study to compare the effectiveness of mastery instruction to an equivalent non-mastery mode of instruction for improving students' learning and retention of selected science process skills was conducted by **Brooks** (1982). The process skills included the lower levels of observation, classification, and prediction, and the higher level, skills of data analysis and hypothesizing. Ninety average and above average junior high school students were involved in the study. No significant differences were found in levels of achievement between mastery and non-mastery-instructed students. Above average mastery-instructed students scored significantly higher than did their non-mastery counterparts in retention of low level process skills, but there was no significant difference in retention for the average students. Both average and above average mastery-instructed students scored higher on retention of the higher process skills than did the non-mastery-instructed students. While mastery instruction did not result in greater achievement gains, the evidence suggests that the mastery instruction strategy may result in a more permanent mastery of the higher process skills than an equivalent time non-mastery instructional strategy.

A study to determine the effectiveness of televised instruction as an aid in changing attitudes toward problem solving was reported by **O'Brien** (1973). The study attempted to find whether fifth and sixth grade students would demonstrate significant differences in: (1) attitude toward the nature of problem solving, (2) self-confidence in solving subsequent problems, and (3) responsibility for success in problem solving. A total of 153 students participated in experimental and control groups in urban and rural schools.

Televised instruction was found to be modestly successful in the urban setting, but regular classroom instruction was superior in changing attitudes in the

rural setting. Participants in on-going activities in subject matter areas provided better continuity in control classrooms, thus facilitating attitude change. The television sessions may not have been conducted over a long enough period of time to measurably change attitudes.

Cox (1981) studied early adolescent use of selected problem solving skills using microcomputers. The subjects included 66 seventh and eighth grade students in four urban junior high schools; 48 were males, 18 were females. Three interactive problem solving microcomputer programs using topics from life science, social science, and environmental education were constructed by the researcher. A training program to organize data using a matrix was also developed to determine the effect of controlled interactive training on the solution of given problems. The students were randomly assigned to either work alone or in groups of two, three, or five for three 50-minute sessions.

Cox concluded, among other things, that: (1) students can improve in problem solving skills in a short time on a microcomputer; (2) the training program on organizing data in a matrix was successful; (3) individuals worked better in teams than alone; (4) the influence of group interaction enabled subjects of all abilities to successfully participate and solve problems; (5) all subjects adapted quickly and easily to use of the microcomputers; and (6) microcomputers can be considered a viable motivating aid for the development of some problem solving skills of early adolescents.

Friedler, Nachmias, and Songer (1989) reported on a study that was part of an investigation of the educational potential of Microcomputer-Based Laboratories (MBL). This study focused on the development and implementation of a scientific reasoning Skill Development Module, which was defined as a series of computerized and non-computerized activities geared toward the instruction of general scientific skills such as experimental planning, prediction formation and revision, control of variables, and the formation of discriminating observations. Microcomputers were used: (a) as a medium for playful learning through game-like activities, and (b) for real time data collection using MBL heat and temperature probeware/software kits. The module was implemented over a period of 16 weeks in eight eighth-grade classes (n=250).

Evaluation of the modules showed an improvement in student abilities to plan, to control variables while designing an experiment, to make careful observations, to distinguish between observations and inferences, to make detailed predictions and to justify them on the basis of their previous experiments. It was found that efforts to explicitly teach strategies for general problem solving skills "were largely successful." The data suggested, however, that students had difficulty transferring general problem solving skills from one context to another. These results support the contention that basic scientific reasoning skills should be taught within a variety of contexts.

Path analysis was used by **Pizzini and Shepardson** (1992) to compare the classroom dynamics (class setting, lesson structure, student interactions, and student behaviors) of a traditional laboratory and a problem-solving Search,

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Solve, Create, and Share (SSCS) model of instruction (Pizzini, Shepardson and Abell, 1989). Class setting was based on small-group/large-group settings. Lesson structure variables were problem finding/refining, research designing, data collecting, data analyzing, and evaluating. The student interaction variables were based on student-student interactions or teacher-student interactions. Student behavior variables consisted of attending, responding, following, soliciting, and giving. Students were randomly selected from several eighth grade life science classes, and observed in five different problem-solving (SSCS) and five different traditional laboratory activities. The problem-solving model included 42 students, the traditional model involved 29.

Path analysis indicated a difference in classroom dynamics of the two instructional models. In both approaches, small-group class settings appeared to encourage student-student interactions, whereas large-group class settings encouraged teacher-student interactions. In the SSCS problem-solving model of instruction, student behaviors were directly influenced by the lesson structure. It was suggested that the lack of correlation between lesson structure and student behaviors in the traditional model may have been due to the use of prepared materials and procedures designed to verify concepts. The SSCS problem-solving instructional model is less teacher directed and procedurally structured, encouraging students to become involved in their own learning. "Thus, student behaviors, in part, are due to students responding to aspects of the lesson structure, that is, undertaking the behaviors necessary to solve problems in science" (p. 257).

Pirkle and Correll (1990) were interested in the performance of early adolescent students on the "Flight Protocol," with particular attention to interpretation of the graphs of paths of projectiles, as well as the comparative effects of the teachers' use of verbal intervention strategies. Eighth grade students (n=30) volunteered to participate and were assigned to one of three groups (half were boys and half were girls in each group). Each group was administered a version of the Flight Protocol, which is composed of a problem sequence in which the students make predictions about the motion of falling or rolling objects or projectile paths. The predictions are presented as graphs, and the students are then allowed to compare their predictions with a computer representation of the same motion. Version I of the treatment allowed minimal intervention by the interviewer. Version II involved the interviewer in episodes of cognitive modeling during which the subject would be informed of how the interviewer thought about the solution to the problem. Version III involved the interviewer in asking, from a script, an additional set of probing questions aimed at comparing the subject's predictions with those represented by the computer.

The results showed that there was no significant difference in performance on the Flight Protocol by the three groups of subjects. Neither cognitive modeling nor probing questions appeared to significantly enhance these subjects' performance. The subjects performed poorly on this activity regardless of the verbal strategies employed by the interviewer. Inspection of the students'

drawings revealed that the students' ability to restructure and transform the information graphically presented, a skill associated with inherent perceptual style, appeared to have a more consistent impact upon success in this task than the use of a verbal intervention strategy.

Novak, Gowin, and Johansen (1983) explored the use of concept mapping and knowledge of Vee mapping with seventh and eighth grade science students. Specific questions addressed were: (1) Can seventh and eighth grade students learn to use concept mapping and Vee mapping strategies in conjunction with regular science programs? (2) Will students' acquisition of science knowledge and problem solving performance change as a result of instruction in the strategies? Instructional sequences were provided to introduce both concept mapping and Vee mapping. Use of such mapping then continued throughout the year with the frequency of mapping varying from teacher to teacher. Maps constructed by the students were collected and scored by applying an "ideal" map as a template to judge student maps. To determine the effect of the learning strategies on transfer of problem solving performance, a series of evaluation measures requiring higher levels of performance (as described by Bloom's taxonomy) were devised. It was found that, in general, students of any ability could be successful in concept mapping and that other factors (e.g., motivation) were more important. Both seventh and eighth graders could acquire an understanding of the Vee heuristic and apply the learning tool in regular junior high school science. An important finding was that the experimental classes demonstrated superiority in problem solving performance on novel problems after less than six months of instruction with these strategies. The data suggested that concept mapping and Vee mapping were helpful with respect to changes in student knowledge about science and problem solving skills, and performance on novel problem solving tests. But the data also indicated that effective use of the Vee heuristic takes time for students to acquire and that two or more years may be required for students to achieve high competence.

A study to compare the relative effects of hands-on and teacher demonstration laboratory procedures on ninth graders' declarative knowledge (factual and conceptual) and procedural knowledge (problem-solving) achievement was conducted by **Glasson** (1989). He particularly wanted to determine whether these relationships varied as a function of reasoning ability and whether prior knowledge and reasoning ability (measured by TOLT) predicted student achievement. The students (n=54) were randomly assigned to classes taught by either a hands-on or a teacher demonstration laboratory method.

He found that: (1) The two instructional methods resulted in equal declarative knowledge (factual and conceptual) achievement. (2) All students in the hands-on laboratory class performed significantly better, regardless of reasoning ability, on the procedural knowledge (problem-solving) test than did students in the teacher demonstration class. (3) Prior knowledge significantly predicted performance on the declarative knowledge test. (4) Reasoning ability, prior knowledge, and teaching method (in that order) all showed significant effects for

procedural knowledge. These three variables accounted for 53% of the variance in problem solving. Glasson concluded that the ability to solve problems is enhanced if students have applied reasoning strategies in the process of actively performing an experiment.

Baker and Piburn (1988) conducted a study to identify factors responsible for a perceived decline in ninth grade students (n=83) attitudes toward science observed in an intervention study designed to enhance scientific literacy. The intervention consisted of a series of skills taught in a developmental sequence from easiest to most difficult. Students then received content lessons that required the use of the skills. The lessons were hands-on, problem solving activities. Students did not have a traditional text or laboratory book. Evaluation consisted of both a Likert-type scale and open-ended response questions.

Although the course was successful in teaching scientific literacy skills and had a positive effect on general cognitive abilities, there was a sharp decline in attitude toward science between the beginning and end of the course. Negative attitudes toward science were found to be related to the demand characteristics of the scientific literacy course, which emphasized problem solving. The researchers concluded that the problem solving nature of the class, learning to think, and, to a lesser extent, the perception on the part of the students that the course had no real life applications contributed to the decline in attitude.

Based on the premise that hypothesis formation is an important step in problem solving, **Quinn and George** (1975) conducted a study to evaluate a method for teaching hypothesis formation to sixth grade children. A Hypothesis Quality Scale was constructed by the authors to evaluate the students' hypotheses. Four intact sixth grade classes were involved: two classes in a low socioeconomic urban area and two in an upper socioeconomic suburban area. Treatment consisted of 12 film and six discussion sessions to teach the children how to formulate hypotheses.

Quinn and George concluded, among other things, that (1) hypothesis formulation can be taught; (2) the quality of the hypotheses can be measured with the Hypothesis Quality Scale; (3) given instruction, lower socioeconomic children do as well as do upper socioeconomic children in the skill of hypothesizing; and (4) the ability to hypothesize is correlated with intelligence, overall grade point average, reading ability, and sex.

In a related study, **Quinn and Kessler** (1980) examined the effects of bilingualism on the ability to formulate scientific hypotheses or solutions to science problems by sixth grade students. The results indicated that (1) the treatment groups performed significantly better than did the control groups; (2) there was no significant difference between the socioeconomic groups; and (3) the bilingual children performed significantly better than did the monolingual children at both high and low socioeconomic levels.

The authors suggest that students educated in more than one language will be better problem solvers than their monolingual peers, which would imply the need for closer working relationships between science and language educators.

Egolf (1979) examined the effects of two modes of instruction on seventh and eighth grade students' abilities to solve quantitative word problems in science. The treatment group included 420 students, the control group, 105 students. Researcher-developed booklets were used to teach the students how to solve a specific type (density) of word problem and to teach a general method for solving word problems.

Among the conclusions drawn were: (1) the booklets could be effectively used to teach students how to solve density problems; (2) no booklet successfully taught the students a general problem solving process; (3) significant grade level effects existed regarding word problem solving ability; and (4) student gender was not related to word problem solving ability.

An instructional program based on expert-novice differences in experimental problem solving performance was taught to sixth grade students (n=265) by **Ross and Maynes** (1983b). Based on a chronological account of what successful scientists do when designing an experiment, the domain of problem solving was broken into a set of seven skills. The first two skills, (1) developing a focus for the investigation (hypothesis formulation), and (2) establishing a framework for the investigation (including control of variables), were selected for inclusion in the instructional design. Classes were randomly assigned to early (between first and second testing periods) or delayed (between second and third testing periods) treatment conditions of instruction. A hierarchy of cognitive behaviors (levels of intellectual performance) that could be reasonably expected of sixth grade students was developed based on the differences between expert and novice problem solvers. The instructional treatment included identifying causes and effects in experimental questions, rewriting inadequate questions, manipulating equipment, and teaching operations of the identified hierarchy of cognitive behaviors such as identification of a potential effect, measurement of the effect, etc. Performance was measured by tests of specific transfer; that is, the same skills were to be performed in a different experimental setting using different apparatus.

It was found that treatment condition students consistently outperformed control group students. The investi-gators concluded that the instructional program had a beneficial effect.

Lawsiripaiboon (1983) examined the effects of a problem solving strategy on ninth grade students' (n=423) ability to apply and analyze physical science subject matter. The problem solving group received problem solving laboratory activities and classroom discussions emphasizing the application and analysis levels. The conventional group received laboratory activities and discussions focusing on the knowledge and comprehension levels. A 50-item multiple-choice achievement test, designed to measure the knowledge, comprehension, application, and analysis levels of understanding, was administered before and after the treatment. It was found that the problem solving group significantly outperformed the conventional group, and that teachers in the problem solving group asked significantly more high level questions.

The investigator concluded that the problem solving strategy used in the study seemed to be an effective means for improving overall achievement, particularly achievement at the application and analysis levels. Problem solving laboratory activities and teacher initiated questions at the application and analysis levels thus appeared to be practical strategies to implement.

A similar study was reported variously by **Russell** (1979), **Russell and Chiappetta** (1980, 1981), and **Chiappetta and Russell** (1982). The purpose of the study was to improve eighth graders' ability to apply and analyze earth science subject matter. Fourteen sections of students (n=287) were randomly assigned to seven experimental and seven control groups taught by four teachers. The experimental groups received a problem solving form of instruction that included reading, problem solving tasks, and discussion and laboratory exercises emphasizing application and analysis levels. The control groups received a traditional textbook oriented form of instruction that included reading, discussion, and laboratory activities. A 40-item achievement test, with ten items at each of the knowledge, comprehension, application, and analysis levels, was administered to determine the effects of the treatment.

The experimental group was found to have significantly outperformed the control group. A comparison of the median questioning level of the teachers showed that the teachers in the experimental group employed a significantly higher level of questions. The investigators concluded that an instructional program using a problem solving approach will significantly increase overall achievement, particularly achievement at the application and knowledge levels, and that such an approach should include written problem solving activities and teacher directed questions that emphasize application of knowledge.

An investigation of the effects of intensive instruction on the ability of ninth grade students (n=205) to generate written hypotheses and ask questions about variables pertaining to discrepant scientific events was reported by **Pouler** (1976) and **Pouler and Wright** (1977). The students were randomly assigned to a control and four experimental groups of 41 students each. The experimental instruction involved watching a discrepant event (a Suchman filmloop) until six acceptable hypotheses were written. The hypotheses were then evaluated by the investigator according to standards that reflected the type of reinforcement and instruction the student was to receive (e.g., the student might be told that the hypothesis was excellent and told the criteria for an acceptable hypothesis).

After instruction, all groups were shown two different discrepant events and asked to write hypotheses for one and questions for the other. Five days later another filmloop was shown to all students who were then allowed to ask the investigator information-gathering questions that could be answered "yes" or "no." It was found that reinforcement was essential for producing a greater quantity of written hypotheses. For higher quality hypotheses, reinforcement plus knowledge of the criteria was superior to no instruction.

In a related study, **Wright** (1978) examined the feasibility of intensive instruction in either the observation of details or hypothesis generation, using a

discrepant event filmloop, as a model for improving the open exploration skills of ninth graders. The study measured five dependent variables: (1) a tally of the number of details, (2) hypotheses, (3) questions, (4) calculation of question density, and (5) average rating of hypothesis quality. One hundred-twenty ninth graders were randomly assigned to two treatment groups and a control group. Each subject individually viewed the Suchman filmloop, "The Balloon in the Jar," after which the investigator solicited details (Treatment One) or hypotheses (Treatment Two). Each response was positively reinforced if it (a) described a relevant detail or acceptable hypothesis, and (b) had not been previously reported. Immediately following instruction, each subject was posttested through the random showing of three additional Suchman filmstrips and allowed to volunteer, as appropriate, details (filmloop, "The Five Pendulums"), questions ("The Spring"), or hypotheses ("The Sailboat and the Fan"). Control group subjects were administered the same posttest.

In general, it was found that the treatment groups were superior to the control group in number of details reported, number and quality of hypotheses generated, and in number and diversity of questions asked. No significant differences were found between treatment groups in terms of the number and quality of hypotheses or the number and diversity of questions generated. Wright concluded that both treatments were equally effective in improving the open exploration skills of the students, with the exception of the number of observed details, in which case the subjects who had been instructed in observing details exhibited superior performance.

McKenzie and Padilla (1984) investigated the effects of three instructional strategies and student entry characteristics on student engagement and the acquisition of skills necessary for the construction and interpretation of line graphs. The strategies examined were an activity-based approach, a written simulation-based approach, and a combination of activity- and written-simulation instruction. Students' (n=101) entry characteristics examined included level of cognitive development and spatial ability. The results indicated that: (1) no single instructional strategy of those examined appeared to be superior to the others in regard to level of graphing achievement attained by students; (2) instructional strategies consisting of activities and written simulations resulted in higher levels of engagement than instruction consisting only of written simulations; (3) students classified as transitional/formal tended to score higher than concrete operational students on the graphing achievement measure; (4) spatial scanning ability showed minimal relationship to graphing achievement; and (5) although differences in engagement across the three treatment groups accounted for a portion of the variance in graphing achievement, the treatments themselves accounted for a unique portion of the variable; this was also true across levels of development.

Butts and Jones (1966) studied the effectiveness of inquiry training in producing more effective problem solving behavior in sixth grade students (n=109). Specific questions to be answered were: (1) whether students exposed

to guidance designed to help them enhance their problem solving behaviors showed more effective problem solving behaviors following such training; (2) whether factors such as IQ, chronological age, or factual knowledge of science were related to change in problem solving behaviors; and (3) whether students exposed to instruction showed behavior patterns indicating meaningful concept development. Approximately half of the students were involved in a planned guidance program based on that devised by Suchman as inquiry training. The remaining students served as the controls and did not receive the inquiry training. All students were administered the *Sequential Test of Educational Progress* (STEP); the *National Achievement Test, Elementary Science Test*; and the *Tab Inventory of Science Processes* (TISP), as pre- and post-tests. It was found that there was a significant relationship between inquiry training and changes in problem solving behaviors as measured by TISP. No relationship was found between inquiry training and changes in concept transfer as measured by TISP, or between inquiry training and recall of factual science knowledge as measured by STEP and the *Elementary Science Test*. No relationship was found between changes in problem solving behaviors that occurred in conjunction with inquiry training and IQ, chronological age, science factual knowledge, or sex.

The investigators concluded that students could benefit from directed instruction in problem solving behaviors and that age, IQ, sex, and science factual knowledge were not significant factors in students' benefitting from inquiry training. The assertion that meaningful concept development results from inquiry training could not be supported; children who were successful problem solvers on TISP could not apply the concept to a different situation.

Jones (1983) investigated what effect acknowledging successful autonomous discovery had upon seventh grade students' problem solving abilities, concept development, science achievement, and self-concept as a learner when they were exposed to the *Inquiry Development Program* for a semester. Forty-nine seventh graders were randomly assigned to two classes (experimental and control), both of which were taught by the investigator. Materials and techniques from Suchman's *Inquiry Development Program* were used with both classes with the exception that in the experimental class successful autonomous discovery was acknowledged by such comments as "right," "ok," or, "that agrees with what most scientists believe at this time." The classes met forty minutes per day, five days per week for fourteen weeks.

Data analyses revealed that: (1) there was no significant difference in changes in self-concept, problem solving behavior, or science concept development between the experimental and control groups; (2) there was no significant change in self-concept or science concept development for either the experimental or control group; (3) a significant difference in the changes in science achievement between the experimental and control groups was found; (4) the control group showed a significant gain in science achievement while the experimental group did not; and (5) there was a significant positive change in problem solving behavior for both the experimental and control groups.

Jones concluded that acknowledgement or lack of acknowledgement of successful autonomous discovery by seventh graders did not significantly affect their self-concept as learners in relation to motivation, task orientation, problem solving, or class membership. Not acknow-ledging successful autonomous discovery resulted in greater science achievement gains than did acknowledgement. Exposure to either technique (acknowledging or not acknowledging autonomous discovery) appeared to significantly increase the problem solving abilities of the students, indicating that the act of discovery was more important than whether or not the discovery was acknow-ledged by the teacher. Neither technique resulted in a significant change in science concept development.

A study was conducted by **Davis** (1979) to examine the effects on achievement of upper elementary school students of using two approaches to science instruction: (1) an expository-text, and (2) a guided inquiry-discovery. In the expository-text approach, the students (n=52) received direct presentation of information and concepts from the text and teachers. In the guided inquiry-discovery approach, the students (n=51), guided by the materials and teachers, engaged in investigations involving inquiry processes structured to develop information and concepts. Two science units with similar content were used with both treatment groups in a manner consistent with the instructional approach assigned to the class.

It was found that: (1) the guided inquiry-discovery approach was significantly more effective than the expository-text approach in achievement of knowledge and information of content contained in the science units; (2) achievement in understanding of science inquiry and processes was slightly, but not significantly, higher for the guided inquiry-discovery group, suggesting that the two methods were equally effective for these students; and (3) students receiving the guided inquiry-discovery instruction expressed significantly more positive attitudes than those expressed by the expository-text group. In conclusion, it appeared that the guided inquiry-discovery method of instruction provided a means of combining the products and processes of science while enhancing positive attitudes.

Thomas (1968) analyzed the effects of two instructional methods, didactic and guided discovery, on the following educational outcomes: understanding of the scientific enterprise, understanding of scientists, understanding of the methods and aims of science, achievement of factual-conceptual understanding, use of critical thinking skills, and use of problem solving skills. Criterion instruments used were the *Test of Understanding Science* (TOUS), a content achievement test, the *Watson-Glaser Critical Thinking Analysis*, and the *TAB Inventory of Science Processes*. Possible interactions of methods with learner variables of sex, intelligence, creativity, interest in science, general scholastic achievement, and achievement in science were also investigated. The sample studied consisted of 143 eighth grade pupils in earth science classes of two teachers.

For the three areas of understanding science, the only difference that could be attributed to method was for understanding of the scientific enterprise, in which case the high group in scholastic achievement was superior when instructed by guided discovery. For factual-conceptual achievement of content, the didactic

method was found to be superior for all pupil variables. For the acquisition of inquiry skills, critical thinking skills, and problem solving, interactions of method with levels of ability showed guided discovery to be better for the high groups and didactic for the low groups with neither being demonstrated as superior for the middle groups.

Using different patterns and amounts of instruction on planning experiments with sixth and eighth grade students, **Padilla, Okey, and Garrard** (1984) examined the effects of instruction on integrated science process skill achievement. Treatment One (n=168) involved a two-week introductory unit emphasizing designing and carrying out experiments. Subsequent content units had approximately one period-long process skill activity per week integrated into the regular curriculum. Treatment Two (n=85) involved only the same two-week introductory unit emphasizing experiments; subsequent instruction was primarily content oriented with little process emphasis. Treatment Three (n=76) was a control treatment receiving the same content oriented instruction as Treatment Two but getting no direct process skill experience. All students were pre- and posttested with the *Test of Logical Thinking* (TOLT) and the *Test of Integrated Process Skills* (TIPS).

All groups were found to increase in process skills achievement and logical thinking over the course of the treatment. No significant process skill (TIPS) differences were found among the three treatments for the sixth graders. Among eighth graders, however, the extended process skill group (Treatment One) scores were found to be significantly higher than scores for either the two-week process skill group (Treatment Two) or the control group (Treatment Three). On the logical thinking (TOLT) variable, no significant differences were found with either grade level; scores from all groups in both grades increased from pre- to posttest, but no differences due to treatment were found.

In order to more closely examine specific skills and the degree to which instruction influenced them, the process skills test was divided into three subtests, and the logical thinking test was divided into five subtests and the data analyzed for these scales. A significant difference due to treatment was found for both sixth and eighth graders on the hypothesizing and identifying variables subtest. Treatment One was found to be higher than the control among sixth graders and both Treatments One and Two were higher than the control for eighth graders. No differences for either grade were found for the other two process skills subtests, nor for any of the logical thinking subtests.

Although the results were statistically significant, relatively little of the sixth and eighth graders' achievement on hypothesizing and identifying variables was accounted for by the treatment. Logical thinking skills were also found to be not much affected in the time span of the treatment. It appeared that affecting one ability had little influence on the other over the 14-week period. It did appear, however, that greater benefit to students seemed to result from integrating science content and process instruction over a longer period of time.

Jordan (1987), using information processing as a theoretical base, sought to determine whether or not specific cognitive strategies could be taught and learned. These strategies dealt with memory skills that had been shown to exist in mature learners. It had been shown that even some university students lacked these basic skills and resorted to ineffective memory techniques. This lack resulted in failure to recall information and an inability to resolve problem solving tasks. Four tasks were designed as follows: (1) summarizing a reading; (2) self-testing vocabulary; (3) writing questions; and (4) writing answers. Grade nine science students (n=311) were assigned to an experimental and a comparison group. Both groups followed an outline based on the Canadian British Columbia Provincial Curriculum for grade nine science. One group was assigned predetermined tasks from the text while the experimental group utilized the designed tasks. The recall and problem solving segments of the posttest comprised the dependent variables while the pretest scores in grade eight science and the Arlin Test of Formal Reasoning constituted the independent variables.

The results showed statistically significant differences in favor of the comparison group on recall and the experimental group on problem solving. Further analysis indicated that while the results were statistically significant, mean score differences were very small. It was observed that while the results might be statistically significant, they also might be educationally questionable.

Linn, Clement, Pulos, Sullivan (1989) assessed the role of science topic instruction combined with logical reasoning (control of variables) instruction in teaching adolescents about blood pressure problems. The sample comprised 35% nonwhites, 50% ninth- graders, 34% tenth-graders, and 16% eleventh-graders. The students were separated into three groups: (a) all groups served as the pretest group and received all tests before science topic instruction; (b) some students served as the posttest group, receiving the tests after blood pressure knowledge instruction; (c) the other students served as the strategy posttest group, who received individual strategy instruction in the controlling-variables strategy, then the blood pressure knowledge instruction, and finally the tests given to the other groups.

Four major findings emerged from this study: (1) All participants acquired science topic knowledge about blood pressure. (2) Those receiving strategy instruction acquired knowledge of the controlling-variables strategy. (3) Acquisition of science topic knowledge influenced reasoning performance. (4) The combination of science topic knowledge and strategy instruction produced more generalized reasoning performance than did science topic knowledge alone. Thus, based on these results, both science topic knowledge and strategy instruction increase the likelihood of successful performance by helping students bring relevant information to bear on problem-solving.

Farrell (1988) sought to determine whether skills in proportional reasoning taught to eighth graders (n=115) before they received instruction in three physical science problems would promote transfer of learning among the problems. The treatment materials were self-instructional packets that included explanations,

diagrams, drawings, and problems on the balance beam, the inclined plane, and the hydraulic lift. The subjects were pre- and posttested, with a random-half of each treatment group receiving additional instruction in fractional proportions.

Students who received instruction in proportionality exhibited greater learning than did uninstructed subjects. In each of the tasks, there was greater transfer of learning to new problems for the students receiving prior instruction in proportionality. It did not appear that transfer was task specific within the context of this study.

A series of separate but coordinated meta-analyses of science education research that analyzed some 250 studies involving more than 50,000 students was conducted (**Anderson et al.**, 1982; **Anderson**, 1983). Four basic steps are involved in the use of meta-analysis: (1) reviewers first locate studies of an issue, using clearly specified procedures; (2) the outcomes of the studies are characterized in quantitative terms; (3) as many features of the studies as possible are coded; and (4) statistical procedures are used to summarize findings and relate study features to study outcomes (**Kulik**, 1983, p. 957). The statistical procedure in meta-analysis involves calculating a common measurement for each defined variable within a study. This common measurement is called an "effect size." Thus, for example, effect size measures the difference in performance of two groups on a dependent variable such as problem solving, achievement, or student attitudes (Kyle, 1984, p. 9). This allows conclusions to be drawn from many studies based upon this common measurement.

The potential for improving science instruction by altering teaching was reported by **Willett, Yamashita and Anderson** (1983) as a result of their meta-analysis of 130 studies of various teaching systems. The most successful systems appeared to be mastery learning and the personalized system of instruction (PSI). For the three outcomes of science methods, critical thinking, and logical thinking, an average effect size of 0.29 was found in favor of the instructional system over traditional approaches. The mean effect size produced over all systems was 0.10, indicating that, on the average, an innovative teaching system in this sample produced one-tenth of a standard deviation better performance than did traditional science teaching. (p. 404)

Wise and Okey (1983) examined the effects of various science teaching strategies on achievement. Teaching methods were defined as being narrower, less encompassing than instructional systems; thus, teaching methods referred to limited aspects of a teaching plan. Twelve categories of teaching techniques were defined: audio-visual, focusing, grading, inquiry, manipulative, modified, presentation approach, questioning, teacher direction, testing, wait-time, and miscellaneous. A total of 76 variables were coded for 160 studies, yielding 400 effect sizes. "The main effect size overall was 0.34. Thus, for all samples considered the experimental science teaching techniques on the average resulted in one-third of a standard deviation improvement over traditional techniques." (p. 419) Based on an effect size analysis of teaching strategies:

> The effective science classroom appears to be one in which students are kept aware of the instructional objectives and receive feedback on their progress toward these objectives. Students get opportunities to physically interact with instructional materials and engage in varied kinds of activities.... Students have some responsibility for defining tasks. (p. 434)

Finally, **Curbelo** (1984) conducted a meta analysis of 68 experimental studies, producing a pooled sample size of 10,629 students, to determine the effects of problem solving instruction on science and mathematics student achievement. The author concluded that:

1. When groups of students were given instruction in problem-solving, their achievement exceeded that of students not provided with instruction in problem-solving by an average of 0.54 standard deviations.

2. The duration of instruction in problem-solving is positively correlated with performance on problem-solving measures.

3. The most effective duration for instruction in problem-solving appears to be 5 to 10 weeks.

4. Problem-solving can be taught effectively in any topical area in science and mathematics.

5. The inquiry method seems to be one of the most effective strategies for teaching problem-solving (p. 78).

Summary

Most middle/junior high school students are probably develop- mentally unable to benefit from instruction in a general problem solving approach. The research shows, however, that students do benefit from instruction in problem solving; they can and do learn to use integrated science process skills. They also are able to transfer these skills to new problems if the new problems are not too dissimilar from those with which the students have had experience. The most effective approach to teaching science appears to integrate science process skills and science content over several weeks duration, using hands-on, inquiry activities concentrating on specific problem solving skills. Moreover, students who receive such instruction tend to learn more science and to develop more positive attitudes toward science and more self confidence in their own abilities.

Science Curricula and Problem Solving

In tracing the historical development of problem solving as a curriculum goal, **White** (1978) notes that it has received attention as a major curriculum strand from the Dewey School of 1896 to the 1970's. As the current effort indicates, concern with problem solving among science curriculum developers has persisted into the 1990's.

Junior high school science curriculum developments in the 1960's departed from traditional methods as well as traditional objectives. The new objectives were directed toward the development of the ability to solve problems in a logical manner. The relationship between inquiry teaching, as represented by the then newly developed science curricula, and intellectual development was studied by **Friot** (1971). Tasks described by Piaget and Inhelder were used to evaluate the development of inter-propo-sitional logic, i.e., formal operations. The tasks were administered at the beginning and end of the 1969-70 school year to eighth and ninth grade students who were enrolled in science courses using the new science curricula. Control groups taking general science were evaluated at each grade level. The study showed that logical thinking processes could be evaluated using the Piagetian tasks and that some curricula were effective at some grade levels but not at others. The *Time, Space and Matter* (TSM) curriculum was significantly more effective in enhancing the development of formal operations than were either the Introductory Physical Science (IPS) or the *Earth Science Curriculum Project* (ESCP) materials. The IPS curriculum was found to be significantly better than the ESCP curriculum. At the ninth grade level, both the ESCP and IPS curricula were significantly better than the control and the IPS curriculum was significantly better than the ESCP curriculum. It was also found that sex and IQ were not significantly related to gains in logical thinking ability.

Schlenker (1971) reported an investigation to determine whether a physical science inquiry development program, based on materials developed at the University of Illinois, achieved significantly different results than a traditionally taught program using similar science content when taught to pupils in grades five through eight. Specific objectives for which comparisons were made were: pupil understanding of science and scientists, fluency and productivity in using the skills of inquiry or critical thinking, and mastery and retention of knowledge of the usual content of elementary school science. The sample included 582 pupils organized in 14 classes, four each of fifth and sixth graders and three each of seventh and eighth graders, assigned as experimental classes and a similar number of control pupils and classes. Test instruments used were the *Test on Understanding Science*, the *Test of Science Comprehension*, the *Questest*, and the *Stanford Achievement Test*, Science Form W.

Schlenker concluded that children who studied under the inquiry development program developed a significantly greater (1) understanding of science and scientists and (2) fluency and productivity in using the skills of inquiry or critical thinking than did children who studied under the traditional program; and that

there was no consistently significant difference in the (3) mastery or (4) retention of the usual content of elementary school science between students who studied under the inquiry development program and students who studied under the traditional program.

Butzow and Sewell (1971) administered the *Test of Science Processes* as a pre- and posttest to 92 eighth graders studying the first five chapters of the *Introductory Physical Science* (IPS) materials to determine if process learning was significantly changed. The students were assigned to four homogeneously grouped classes with placement based on IQ, teacher recom-mendation, interviews, and achievement records in English and mathematics. All classes were taught by the same teacher.

There were significant improvements in the students' ability to observe, compare, classify, quantify, measure, experiment, and infer during the period of the course, but not in the ability to predict. It appeared that there was a relationship between intelligence and process skills such that the more intelligent groups at the eighth grade level were further along a continuum of difficulty from observing to experimenting at the onset of instruction. Consequently, classes with students having lower ability levels showed the greatest change in process learning during IPS instruction.

A study to compare selected aspects of two seventh grade science programs, *Interaction of Man and the Biosphere* (IMB), an experimental inquiry program, and *Science is Explaining*, the control program, was reported by **Gudaitis** (1971). The study population included two teachers and their eight classes; each teacher had two experimental and two control classes. The experimental group and the control group each consisted of 48 boys and 48 girls. The *Attitude Toward Any Subject* scale was used to measure attitudes toward science; the *Cornell Test of Critical Thinking - Level X*, critical thinking; and the *Test of Science Processes*, science process skills.

From pretest to posttest on attitude toward science, students in the experimental program showed no significant attitude change while students in the control group showed a significant decrease in attitude; there was no significant difference in mean gain scores between the two groups. For science process skills, the mean gain scores for students in both programs showed significant growth; however, there was no significant difference in the mean gain scores between the two groups. For critical thinking skills, the mean gain scores for students in both programs showed significant growth; students in the experimental group made significantly greater gains in critical thinking ability than did students in the control group.

Hill (1982) compared the effect of a *Human Sciences Program* module and traditional science classes on pupils' logical thinking skills and attitudes toward their science course. Pupils in eight intact classes in four junior high schools were included in the study. One teacher at each school taught one experimental and one control class. The students were tested on their attitudes and logical thinking skills prior to the treatment and then posttested following the treatment period.

No significant difference was found between treatment groups in pupils' logical thinking scores; however, a significant teacher by treatment interaction was found. No difference was found between treatment groups on the total attitude instrument; however, a significant difference in favor of *Human Sciences* was found on the activity subscale. A significant sex by treatment interaction was also found. It appeared that the *Human Sciences Program*, when compared to traditional science classes, was partially successful in promoting more positive attitudes. However, the *Human Sciences Program* did no more to promote logical thinking skills than did the traditional science classes.

Heffernan (1973) compared the effects of two methods of science instruction, individualized (ISCS) and traditional (New York State Science Syllabus). Specific concerns were whether there were differences in students' ability to (1) understand the methods and aims of science, (2) understand the scientific enterprise, (3) understand scientists as people, and (4) think critically, and whether there were differences (5) in students' attitudes toward science, and (6) in teacher behavior in the two types of classrooms. Instruments used were Form W of the Test of Understanding Science (TOUS) - Scale 1, to measure understanding of the scientific enterprise; TOUS - Scale 2, understanding scientists as people; TOUS - Scale 3, understanding the methods and aims of science; *Watson-Glaser Critical Thinking Appraisal*, ability to think critically; and *Science Attitude Survey*, student attitude toward science. The data revealed that there were no significant differences between the two groups on any of the TOUS scales, on the *Critical Thinking Appraisal*, or on the *Science Attitude Survey*. Data from the *Science Attitude Survey* indicated a positive attitude toward science for all the students involved in the study. The data also suggested that there may have been a "leak" of teacher behavior from the experimental to the control classes (in the form of an increase in group activity in the traditional class in response to its success in the individualized class).

A study reported variously by **Stallings** (1973) and **Stallings and Snyder** (1977), compared the inquiry behavior of ISCS and non-ISCS students as measured by the *Tab Science Test*. The *Tab Science Test* was administered to 178 seventh grade, 164 eighth grade, and 104 ninth grade ISCS students, and to 165 seventh grade, 113 eighth grade, and 68 ninth grade non-ISCS students. Each grade level in the study was treated as a separate experiment and the Tab Test scores were analyzed by analysis of covariance with IQ and father's education level as blocking variables.

No significant differences were found between ISCS and non-ISCS groups in the seventh or eighth grades; however, a difference in favor of the non-ISCS group was found in the ninth grade. No differences in patterns of clue questions selected were found between the ISCS and non-ISCS groups in seventh or eighth grade. Differences in clue question selection were found in the ninth grade, with the ISCS students exhibiting fewer inefficient patterns and more efficient patterns of inquiry than did the non-ISCS group. The ISCS program as used by teachers involved in this study did not result in clear gains in inquiry skills; however, the

reliability of the Tab Test was found to be low (0.556 for ninth grade, 0.455 in eighth grade, and 0.434 in the seventh grade) suggesting that caution be exercised in interpreting the results.

Evaluation of the *Unified Science and Mathematics for Elementary Schools* (USMES) program was the basis for studies reported by **Shapiro** (1973), **Shann** (1975), and **Shann et al.** (1975). A primary objective of the USMES program "is the enhancement of elementary school student's abilities in real, complex problem solving" (Shann et al., 1975, p. 127). Shapiro (1973) used the Notebook Problem to observe problem solving behaviors of students in grades two through six in 43 experimental and 31 control schools. The Notebook Problem consisted of presenting the students with three notebooks that differed from each other in such dimensions as number of pages, number of lines per page, binding, price, etc. The pupils were asked to (1) select the most appropriate notebook for use in class, and (2) indicate the reasons for this selection.

Pretests and posttests were administered to randomly selected students from both the control and USMES groups. Scoring of responses was based on (1) whether any of the subject's reasons for selection were stated in measurable quantities, and (2) the highest level of warrant associated with the reasons stated. Examples of measurable dimensions included: (1) size-volume, (2) weight, (3) cost, (4) quality, etc.; while levels of warrant were determined by whether responses were: (1) personal opinion, (2) testable, or (3) had been tested. Shapiro reported that "in terms of the two dependent variables studied, the USMES experience had, irrespective of units and teachers involved, a marked and positive effect on the students' problem solving behavior" (p. 13).

During the 1973-74 school year, **Shann** (1975) evaluated the problem solving abilities of five students randomly selected from each of 38 classes which were using the USMES program. The students, working in groups of five, were presented with a catalog of equipment, cost data, and measuring instruments, and asked to develop a plan for a playground that would serve students in their school. Two facets were measured: (1) behavioral assessment, which included motivation to accept the problem, commitment to the task, allocation of responsibility for manpower efficiency, and nature of group leadership; and (2) cognitive assessment, which included four summary rating scores on variable identification, measurement, calculation, and recording. Drawings of the playground plans were analyzed to yield four product scores: scale, labels, landmarks, and area designation. Thus, a total of 12 scores were derived for each test: four behavioral, four cognitive, and four product.

On pretest-posttest comparisons, no significant differences were found on the behavioral aspects; on the cognitive factors of measurement, calculation, or recording; or on product scores. On identification of variables, pretest scores were found to be significantly higher than posttest scores. Interviews with teachers disclosed that teachers perceived children in the USMES program to be more responsible for their own learning, and to show growth in data collection abilities, in graphing skills, in hypothesis testing, and in communication with

their peers. Although not supported by data, these perceptions were consistent and persistent among teachers from all geographic and demographic areas involved in the program.

The USMES program was again assessed during the 1974-75 school year by **Shann et al.** (1975) by evaluating students from 37 USMES and 34 control classes. Instruments included the Playground Problem, used in the prior assessment, and a parallel Picnic Problem. In the Picnic Problem, students were given photos of various foods, cost data, measuring instruments, told that they could spend $25 per student, and asked to plan a picnic for 25 students. The same behavioral, cognitive, and product scores were derived as in the earlier study.

No significant differences were found for behavioral scores in either pretest-posttest or USMES versus control comparisons. A significant increase in cognitive scores was found across grade levels with higher scores associated with higher grade levels, but no significant differences were found between treatment and control groups. For product scores, no significant differences were found for either pretest-posttest or treatment versus control comparisons. There was some evidence that USMES enhanced basic skill development in mathematics, science, and social science as measured by SAT tests. Concern with the validity and reliability of the problem solving instruments led to the development of a separate instrument described in the section on assessment of problem solving. (**Shann**, 1976).

Bullock (1973) reported a study to determine the relative effectiveness of three different types of elementary school science curricula in the development of selected problem solving skills of sixth grade students. The three curricula were: *Science - A Process Approach* (SAPA), the Laidlaw textbook series, and the *Environmental Studies* (ES) project materials. A total of 27 teachers and 512 students participated in the study. Nine sixth grade teachers with 172 students were selected who had received training in the use of the SAPA materials. Eight sixth grade teachers with 163 students used the ES materials. Ten other teachers with 177 students used the Laidlaw textbook series along with any supplementary materials designed by these teachers. The TAB Science Puzzler Form B was administered as a pretest and the TAB Science Puzzler Form C was given as a posttest six months later.

It was found that: (1) there was no significant difference in the improvement of the problem solving skills of students using the Laidlaw textbook series compared to students using the SAPA curriculum materials; (2) there was a significant difference in the improvement of problem solving skills of students using the Laidlaw textbook series compared to students using the ES materials; and (3) there was a significant improvement in the problem solving skills of the students exposed to the SAPA materials compared to those exposed to the ES materials; and (4) significant improvement in problem solving skills was attained with both the SAPA program and the textbook series.

In a related study, the long term effectiveness of SAPA in the development of problem solving skills in fifth and sixth graders was assessed by **Breit and**

Bullock (1974). This was a comparison of certain problem solving skills of children who had been in classrooms using the SAPA program for at least four years with the performance of children who had been in classrooms not using SAPA. A random sample of 100 students from each of the groups was selected for the study. The *TAB Science Puzzler*, Form B, was administered to both groups of pupils. A significant difference in problem solving skills was found in favor of the children who had been using the SAPA materials.

Shaw (1978, 1983) was concerned with determining the effect of the process-oriented science curriculum, *Science - A Process Approach II* (SAPA II), on the ability of sixth graders to utilize problem solving skills, which were defined as the integrated process skills of controlling variables, forming hypotheses, interpreting data, and defining operationally. Other areas investigated included: (1) determining if problem solving learned in science would transfer to social studies, (2) testing models concerning problem solving skills to determine if there was evidence for a hierarchy of problem solving skills, and (3) determining if training in problem solving skills would increase students' proficiency in basic skills such as observing, inferring, predicting, etc. Four classes, two classes of each of two teachers, were selected for the study. Each teacher taught one of the experimental and one of the control classes. The treatment consisted of 11 modules from SAPA II over a period of 24 weeks. The control groups participated in investigator-designed activities covering the same subject matter areas and incorporating the same amount of hands-on activities as the process modules. All students were posttested with two investigator-developed process tests, one in science and one in social studies content areas.

The treatment group scored higher than the control group on the problem solving skills portions of both the science and social studies instruments, indicating that problem solving skills can be taught by the process oriented science curriculum and that these processes will transfer to social studies content. No significant differences between the groups were found on either instrument for basic process skills except that the treatment group scored higher than the control group for the process of classifying on the social studies instrument, but not on the science instrument. Evidence was found to support the hierarchy model of process skills, suggesting that mastery of the basic skills is a prerequisite to proficiency in the problem solving skills.

An analysis of inquiry level within junior high textbooks, supplemental activity guides, and disciplines was undertaken by **Pizzini, Shepardson and Abell** (1991) using an analysis scheme that classifies the inquiry level of activities as confirmation, structured-inquiry, guided-inquiry, and open-inquiry. Confirmation activities require students to verify concepts or principles through a known procedure to be followed. Structured-inquiry activities present students with a problem in which they do not know the results but are given a procedure to follow. Guided-inquiry activities provide the students only with a problem to investigate; the students determine the procedure to be followed and the data to be collected. Open-inquiry requires the students to use science concepts or principles. Textbook

chapter activities were analyzed based on the textual content preceding the activity. Supplemental activities were analyzed based on the textual information within the chapter. The Merrill Focus series and Principle series and the Scott, Foresman series were selected for analysis because they accounted for 44% of the science textbooks used at the junior high level. The science textbooks were evenly divided into four sequential clusters by chapter, from which one chapter in each cluster was randomly selected. All activities within the supplemental activity guides that were designated by the publisher to correspond with the selected textbook chapters were also analyzed for inquiry level.

The findings of this study indicate that the inquiry level of activities within both textbooks and supplemental activity guides and across all disciplines is restricted to the confirmation and structured-inquiry levels, with confirmation level activities dominating. No guided-inquiry or open-inquiry activities were found in any of the textbooks or supplemental activity guides. The authors concluded that it is unlikely that the use of commercially published activities in themselves will contribute to the inclusion of open-inquiry science instruction because of their emphasis on confirmation and structured level inquiry. Thus, the use of commercially published materials as they are produced will do little or nothing to contribute to the development of problem solving skills.

The following three reports are all based upon meta-analyses of other studies and include findings related to other topics as well as to problem solving. Studies of the effects of "new" (inquiry-oriented) science curricula on student performance were synthesized by **Shymansky, Hedges and Woodworth** (1990) in a reanalysis of an earlier meta-analysis (**Shymansky, Kyle and Alport,** 1983). In the original study, new curricula were defined as those programs that:

(a) were developed after 1955 (with either private or public funds)

(b) emphasized the nature, structure, and processes of science

(c) integrated laboratory activities as an integral part of the class routine

(d) emphasized higher cognitive skills and an appreciation of science.

Traditional curricula were defined as those programs that:

(a) were developed or patterned after a program prior to 1955

(b) emphasized knowledge of scientific facts, laws, theories and applications

(c) used laboratory activities as verification exercises or as lesson supplements (1990:131)

Six criterion clusters were used as dependent variables in this meta-analysis: science achievement, student perceptions, process skills, problem solving, related skills (reading, math computation, writing), and other performance areas (involving

mostly studies of Piagetian task performance). "The impact of the new curriculum in terms of an effect-size estimate is the difference between the mean criterion scores for the new and traditional curricula expressed in standard deviation units" (p. 132). Thus, for example, an effect size of 1.0 indicates that a criterion score that would be at the 50th percentile under the new curriculum would have been at the 84th percentile under the traditional curriculum; in effect, the new curriculum raises "C" pupils almost to "A" status (p. 133). The analysis showed that student performance across all curricula at the junior high school level was significantly affected ($p < .05$) for composite (Mean ES=.33), science achievement (Mean ES=.39), process skills (Mean ES=.39), and problem solving (Mean ES=.23). The results of this reanalysis generally support the conclusions of the earlier study: The new science curricula of the 60s and 70s were more effective than the traditional textbook programs of the time.

Science curriculum effects in the secondary school were examined by **Weinstein, Boulanger and Walberg** (1980) in a meta-analysis of 33 studies involving over 19,000 students in the U.S., Great Britain, and Israel. The studies reviewed involved 13 different curricula, eight at the senior high school level and five at the junior high school level. Outcomes considered were: (1) conceptual learning; (2) inquiry skills; (3) attitudinal development; (4) laboratory performance; and (5) concrete skills. Weinstein et al. reported a ratio of approximately 4:1 in favor of outcomes related to the use of innovative curricula and concluded that:

> ...the post-Sputnik (1958) curricula produced beneficial effects on science learning that extended across science subjects in secondary schools, types of students, various types of cognitive and affective outcomes, and the experimental rigor of the research....the present analysis shows a moderate 12 point percentile advantage (effect size = 0.31) on all learning measures of average student performance in the innovative courses. (pp. 518-519)

Bredderman (1983) synthesized the research on the effec-tiveness of three activity-based elementary school science curricula (ESS, SAPA, and SCIS). Outcomes were measured in 57 studies, including over 900 classrooms. "The mean effect size for all outcome areas was 0.35. This indicates about a 14 percentile improvement for the average student as a result of being in the activity-based program" (p. 504). Gains for the activity-based curricula were found for science content, science processes tests, and affective outcomes. Gains were also reported, on the average, in creativity, intelligence, language, and mathematics. Disadvan-taged students derived greater benefits than did other students. The effects of the particular programs reflected their relative curricular emphases (p. 499). Bredderman concluded that:

> The accumulating evidence on the science curriculum reform efforts of the past two or three decades consis-tently suggests that the more activity-process-based approaches to teaching science result in gains over tradi-tional methods in a wide range of student outcomes at all grade levels. (p. 513)

Summary

In most, but not all, cases using inquiry oriented curricula resulted in significant gains in problem solving skills, as well as gains in achievement, and in attitudes toward science. These gains vary, however, from one curriculum to another and from one grade level to another. Yet, when we consider the total picture, we find convincing evidence that the curriculum does make a difference. In short, using a curriculum designed to promote an inquiry approach will result in enhanced problem solving abilities, as well as gains in other outcomes.

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Computer searches: Requests for a computer search should be directed to one of the search services listed in the *Directory of ERIC Information Service Providers*, available from ACCESS ERIC.

ERIC Clearinghouse publications: Requests for a publication produced by an ERIC Clearinghouse should be directed to the specific Clearinghouse.

Major ERIC Products

ERIC produces many products to help you access and use the information in the ERIC database:

Abstract Journals : ERIC produces two monthly abstract journals. *Resources in Education* (RIE), a publication announcing recent education-related documents, and the *Current Index to Journals in Education* (CIJE), a periodical announcing education-related journal articles, is available through Oryx Press (1-800-457-6799). Many libraries and information centers subscribe to both monthly journals.

All About ERIC: This guide provides detailed information on ERIC, its products and services, and how to use them. Free copies are available from ACCESS ERIC.

Catalog of ERIC Clearinghouse Publications: The *Catalog* lists publications produced by the ERIC Clearinghouses and support components, prices, and ordering information. Free copies of the *Catalog* are available from ACCESS ERIC.

The ERIC Review: This journal discusses important ERIC and education-related developments. For a copy, call ACCESS ERIC.

Information Analysis Products : ERIC Clearinghouses produce reports, interpretive summaries, syntheses, digests, and other publications, many free or for a minimal fee. Contact the Clearinghouse most closely associated with your interests for its publications list. Call ACCESS ERIC for a free copy of the *Catalog of ERIC Clearinghouse Publications*.

Microfiche: The full text of most ERIC documents is available on microfiche. Individual documents and back collections on microfiche are available. Call the ERIC Reproduction Document Service (EDRS) for more information.

Thesaurus of ERIC Descriptors - The complete list of index terms used by the ERIC System, with a complete cross-reference structure and rotated and hierarchical displays, is available from Oryx Press.

ERICTAPES- Computer tapes of the ERIC database are available by subscription or on demand from the ERIC Facility (write for a price list).

ERIC Document Delivery

Documents : EDRS is the primary source for obtaining microfiche or paper copies of materials from the ERIC database. EDRS can provide full-text copies of most documents announced in Resources in Education (RIE), and ERIC's microfiche collection is available by monthly subscription from EDRS. EDRS also sells microfiche and paper copies of individual documents on request. For more information, call EDRS at (800) 443-ERIC.

Journal Articles: Two agencies that provide reprint services of most journal articles announced in *Current Index to Journals in Education* (CIJE) are listed below. Some journals do not permit reprints; consult your local university or local library to locate a journal issue. Or, write directly to the publisher. Addresses are listed in the front of each CIJE.

University Microfilms International (UMI)
Article Clearinghouse
300 North Zeeb Road
Ann Arbor, MI 48106
Telephone: (800) 732-0616

Institute for Scientific Information (ISI)
Genuine Article Service
3501 Market Street
Philadelphia, PA 19104
Telephone: (800) 523-1850

ERIC Information Retrieval Services

The ERIC database is one of the most widely used bibliographic databases in the world. Last year, users from 90 different countries performed nearly half a million searches of the database. The ERIC database currently can be searched via four major online and CD-ROM vendors (listed below). Anyone wishing to search ERIC online needs a computer or terminal that can link by telephone to the vendor's computer, communications software, and an account with one or more vendors.

The *Directory of ERIC Information Providers* lists the address, telephone number, and ERIC collection status for more than 900 agencies that perform searches. To order a copy, call ACCESS ERIC (1-800-LET-ERIC).

Online Vendors

BRS Information Technologies
8000 Westpark Drive
McLean, VA 22102
Telephone: (703) 442-0900
(800) 289-4277

Dialog Information Services
3460 Hillview Avenue
Palo Alto, CA 94304
Telephone: (415) 858-2700
(800) 334-2564

OCLC (Online Computer Library Center, Inc.)
6565 Frantz Road
Dublin, OH 43017-0702
Telephone (614) 764-6000
(800) 848-5878
(Ext. 6287)

CD-ROM Vendors

Dialog Information Services (same address as above)

Silver Platter Information Services
One Newton Executive Park
Newton Lower Falls, MA 02162-1449
Telephone: (617) 969-2332
(800) 343-0064

ERIC Components

Federal Sponsor

Educational Resources Information Center (ERIC)
U.S. Department of Education
Office of Educational Research and Improvement (OERI)
555 New Jersey Avenue N.W.
Washington, DC 20208-5720
Telephone: (202) 219-2289
Fax: (202) 219-1817

Clearinghouses

Adult, Career, and Vocational Education
The Ohio State University
1900 Kenny Road
Columbus, OH 43210-1090
Telephone: (614) 292-4353; (800) 848-4815
Fax (614) 292-1260

Counseling and Personnel Services
University of Michigan
School of Education, Room 2108
610 East University Street
Ann Arbor, MI 48109-1259
Telephone: (313) 764-9492
Fax: (313) 747-2425

Educational Management
University of Oregon
1787 Agate Street
Eugene, OR 97403-5207
Telephone: (503) 346-5043
Fax: (503) 346-5890

Elementary and Early Childhood Education
University of Illinois
College of Education
805 W. Pennsylvania
Urbana, IL 61801-4897
Telephone: (217) 333-1386
Fax (217) 333-5847

Handicapped and Gifted Children
Council for Exceptional Children
1920 Association Drive
Reston, VA 22091-1589
Telephone: (703) 620-3660
Fax: (703) 264-9494

Higher Education
The George Washington University
One Dupont Circle N.W., Suite 630
Washington, DC 20036-1183
Telephone: (202) 296-2597
Fax: (202) 296-8379

Information Resources
Syracuse University
Huntington Hall, Room 030
Syracuse, NY 13244-2340
Telephone: (315) 443-3640
Fax: (315) 443-5732

Junior Colleges
University of California at Los Angeles (UCLA)
Math-Sciences Building, Room 8118
405 Hilgard Avenue
Los Angeles, CA 90024-1564
Telephone: (213) 825-3931
Fax: (213) 206-8095

Languages and Linguistics*
Center for Applied Linguistics
1118 22nd Street N.W.
Washington, DC 20037-0037
Telephone: (202) 429-9551 and (202) 429-9292
Fax: (202) 429-9766 and (202) 659-5641
**Includes Adjunct ERIC Clearinghouse on Literacy Education for Limited English Proficient Adults*

Reading and Communication Skills
Indiana University
Smith Research Center, Suite 150
2805 East 10th Street
Bloomington, IN 47408-2698
Telephone: (812) 855-5847
Fax: (812) 855-7901

Rural Education and Small Schools
Appalachia Educational Laboratory
1031 Quarrier Street
P.O. Box 1348
Charleston, WV 25325-1348
Telephone: (800) 624-9120 (outside WV)
(800) 344-6646 (inside WV)
(304) 347-0400 (Charleston area)
Fax: (304) 347-0487

Science, Mathematics, and Environmental Education
The Ohio State University
1200 Chambers Road, Room 310
Columbus, OH 43212-1792
Telephone: (614) 292-6717
Fax (614) 292-0263

Social Studies/Social Studies Education**
Indiana University
Social Studies Development Center
2805 East 10th Street, Suite 120
Bloomington, IN 47408-2373
Telephone: (812) 855-3838
Fax: (812) 855-7901
***Includes Adjunct ERIC Clearinghouse on Art Education; and the National Clearinghouse for U. S.-Japan Studies*

Teacher Education
American Association of Colleges for Teacher Education (AACTE)
One Dupont Circle N.W., Suite 610
Washington, DC 20036-2412
Telephone: (202) 293-2450
Fax: (202) 457-8095

Tests, Measurement, and Evaluation
American Institutes for Research (AIR)
Washington Research Center
3333 K Street N.W.
Washington, DC 20007-3893
Telephone: (202) 342-5060
Fax: (202) 342-5033

Urban Education
Teachers College, Columbia University
Institute for Urban and Minority Education
Main Hall, Room 300, Box 40
525 West 120th Street
New York, NY 10027-9998
Telephone: (212) 678-3433; Fax (212) 678-4048

Adjunct Clearinghouses

National Clearinghouse on Literacy Education
Center for Applied Linguistics
1118 22nd Street N.W.
Washington, DC 20037
Telephone: (202) 429-9292
Fax: (202) 659-5641

Adjunct ERIC Clearinghouse for Art Education
Indiana University
Social Studies Development Center
2805 East 10th Street, Suite 120
Bloomington, IN 47405-2698
Telephone: (812) 855-3838
Fax: (812) 855-7901

National Clearinghouse for U.S.-Studies
Indiana University
Social Studies Development Center
2805 East 10th Street, Suite 120
Bloomington, IN 47408-2698
Fax: (812) 855-7901

Adjunct ERIC Clearinghouse on Chapter 1
Chapter 1 Technical Assistance Center
PRC, Inc.
2601 Fortune Circle East
One Park Fletcher Building, Suite 300-A
Indianapolis, IN 46241
Telephone: (317) 244-8160, (800) 456-2380
Fax: (317) 244-7386

Support Components

ACCESSERIC
Aspen Systems Corporation
1600 Research Boulevard
Rockville, MD 20850-3166
Telephone: (800) LET-ERIC
Fax: (301) 251-5212

ERIC Document Reproduction Service
7420 Fullerton Road, Suite 110
Springfield, VA 22153-2852
Telephone: (301) 258-5500; (800) 443-ERIC
Fax: (301) 948-3695

Oryx Press
4041 North Central Ave., Suite 700
Phoenix, AZ 85012-3399
Telephone: (602) 265-2651; (800) 279-ORYX
Fax: (602) 265-6250; (800) 279-4663

How to Submit Documents to ERIC

ERIC collects a variety of materials on education-related topics. Examples of materials included in the database:

Research reports
Instructional materials
Monographs
Teaching Guides
Speeches and presentations
Manuals and handbooks
Opinion papers

Submissions can be sent to the Acquisitions Department of the ERIC Clearinghouse most closely related to the subject of the paper submitted, or sent to the ERIC Processing Facility.

About the author

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